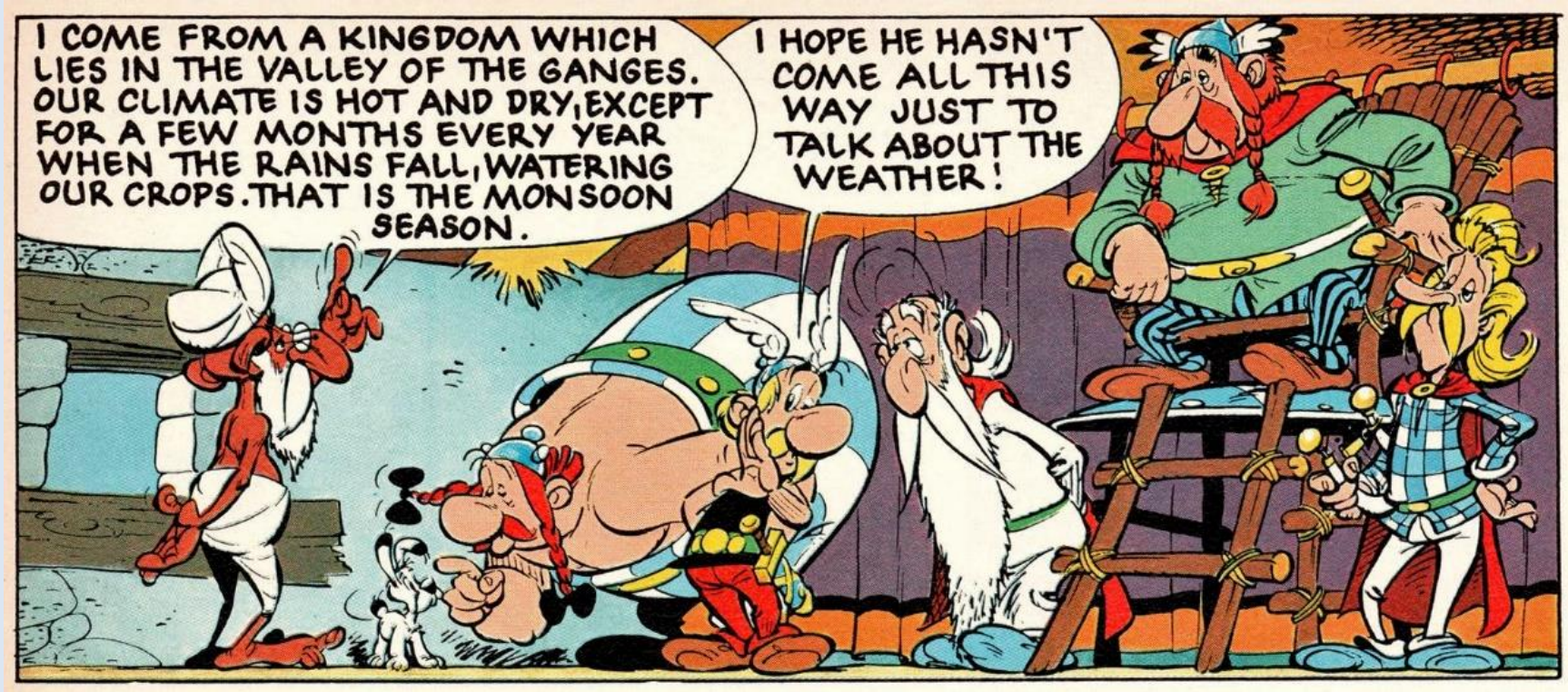
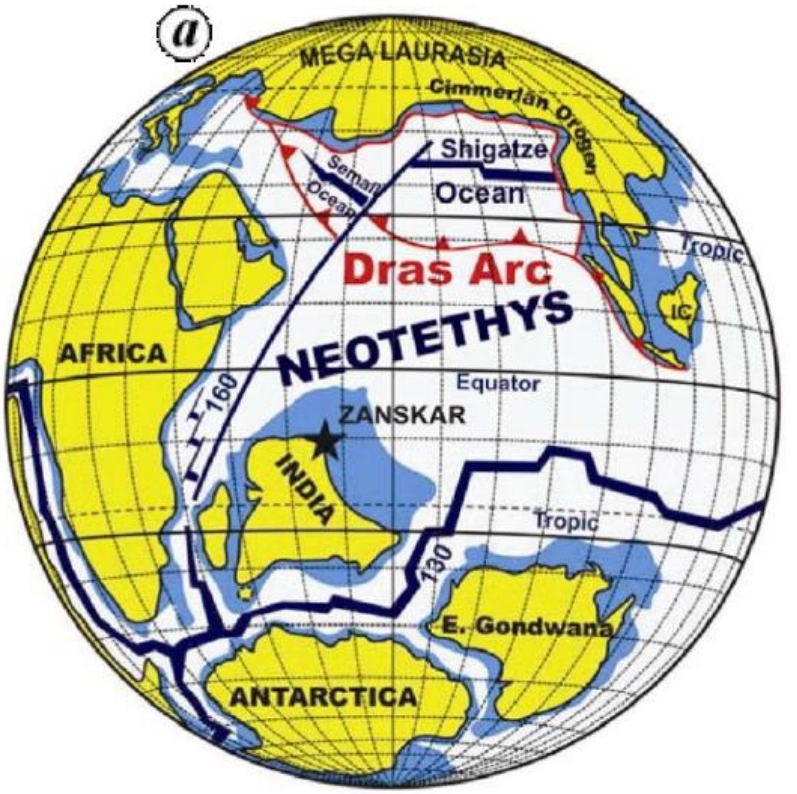
Indian Ocean warming – its extent, and impact on the Monsoon and Marine Productivity

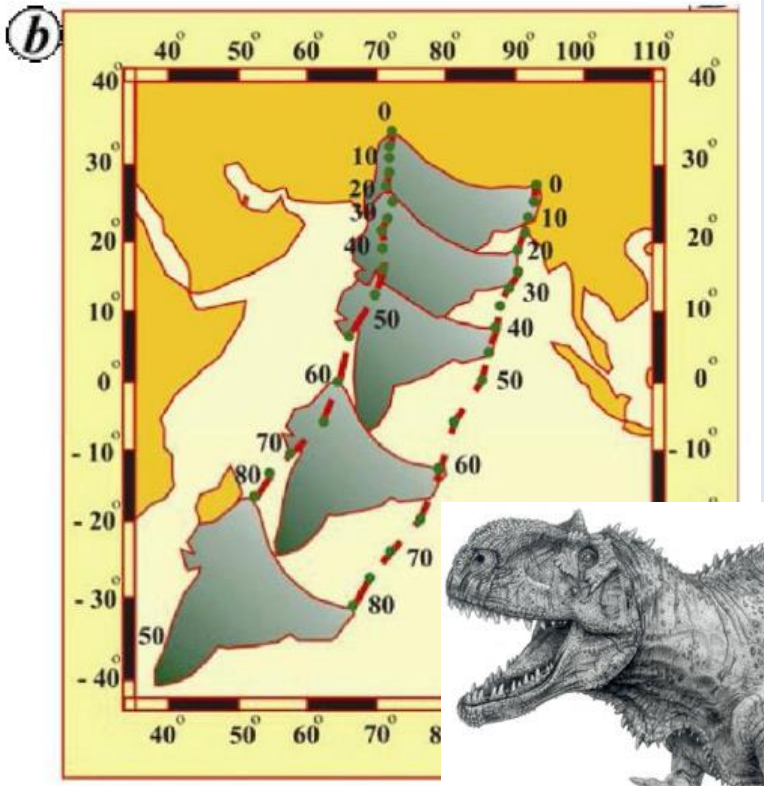


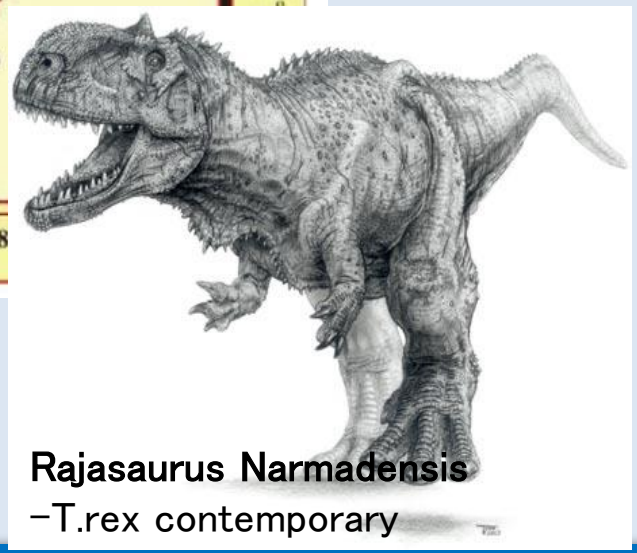
Climate Change Training
for Indian Foreign Service [IFS] Probationers

Roxy Mathew Koll
Indian Institute of Tropical Meteorology, Pune

History of Monsoon, 80 Mya
Plate tectonics - factors leading to modern monsoon





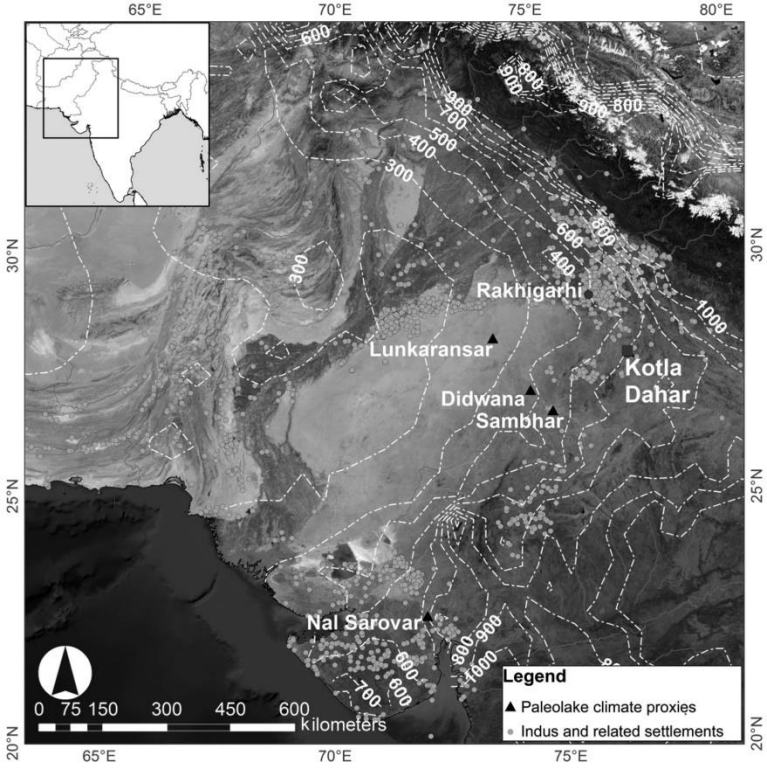

Rajasaurus Narmadensis
–T.rex contemporary

Indian plate motion: rate of ~ 15cm/yr – collided with Asia c.20–30 Mya.
Copley et al. *JGR,* 2010; Jain *Curr.Sci.,* 2014

Some remnants of Deccan volcanism

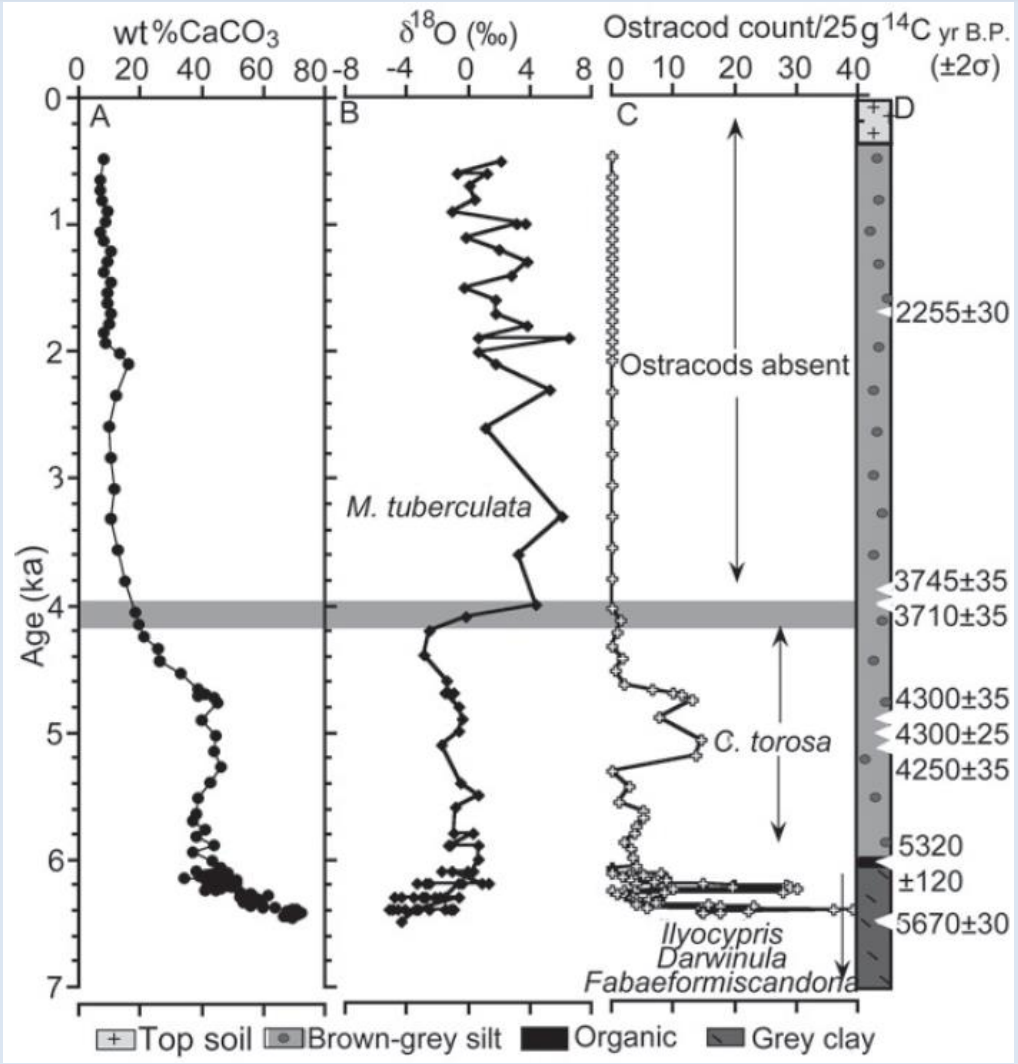
Layers of basaltic lava deposits – Mahabaleshwar, Maharashtra

History of Monsoon, 4.1Kya
Monsoon weakening in NW and collapse of Indus Valley



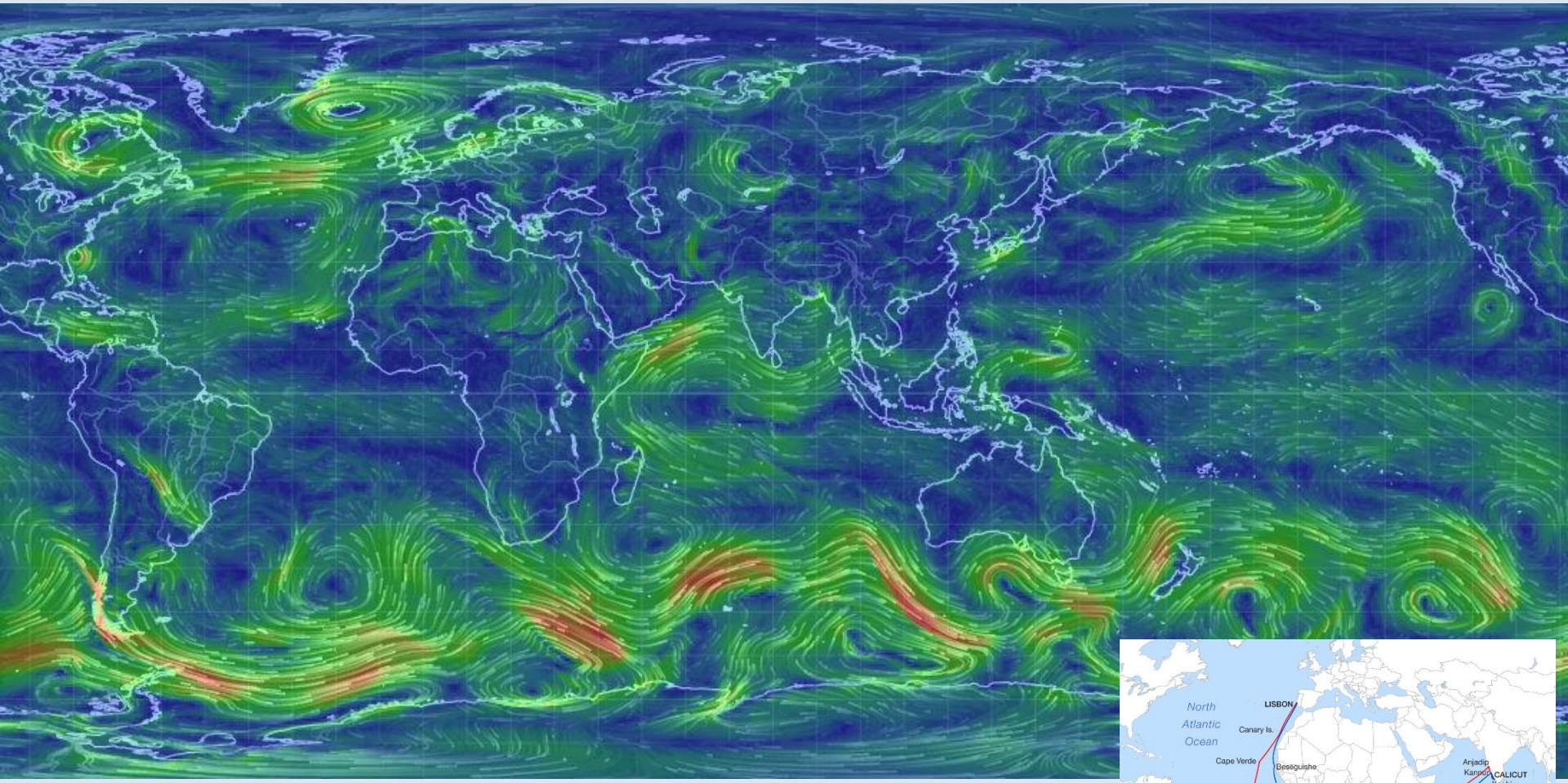
Variation in the timing and intensity of the monsoon affects lake–water Oxygen isotope and alters relative hydrologic balance between evaporation and precipitation in the lake.

Presence/absence of ostracods confirms this.



Dixit et al., *Geology*, 2014

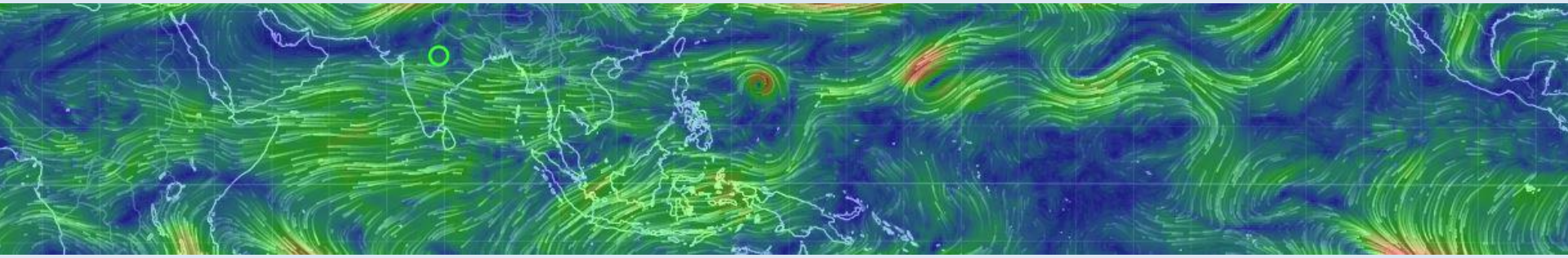
Monsoon, manifested by Winds
Trade Winds



850 hPa wind flow during July 2014

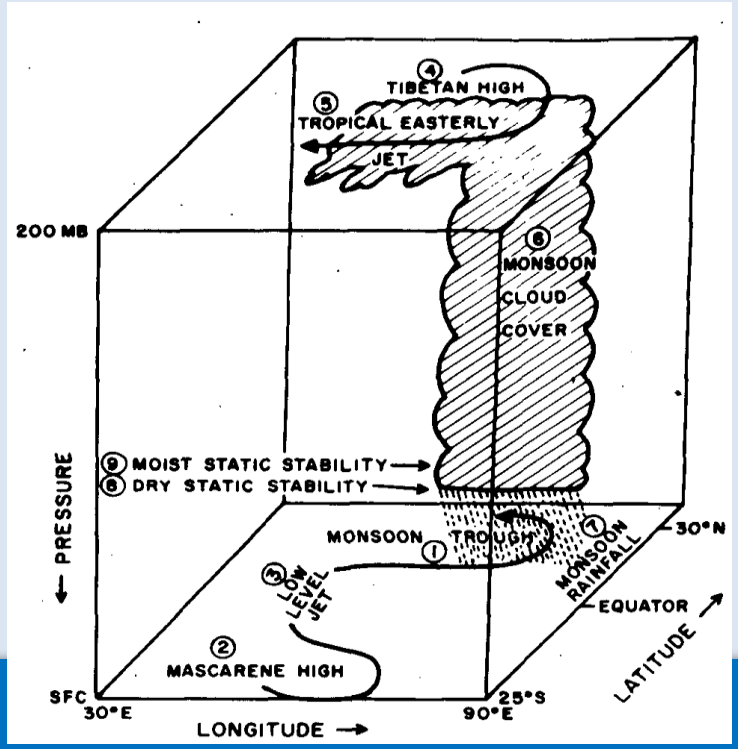
Monsoon, Tropical Easterly Jet

Low-level convergence matched by upper level divergence

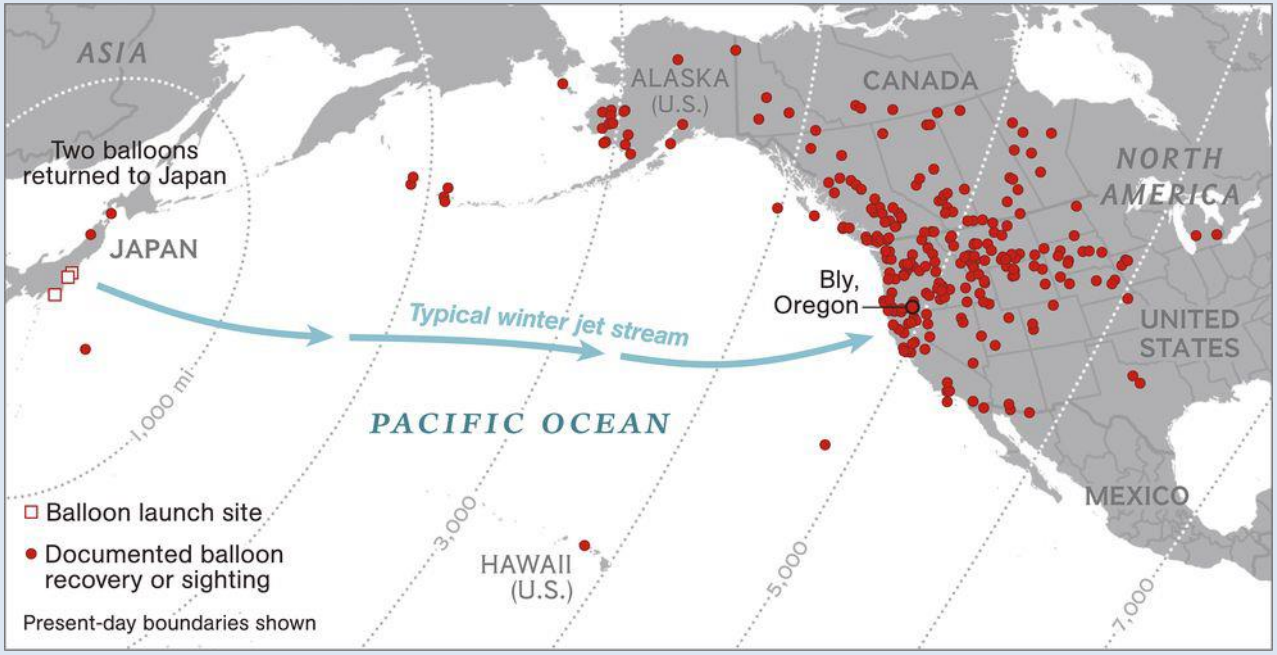


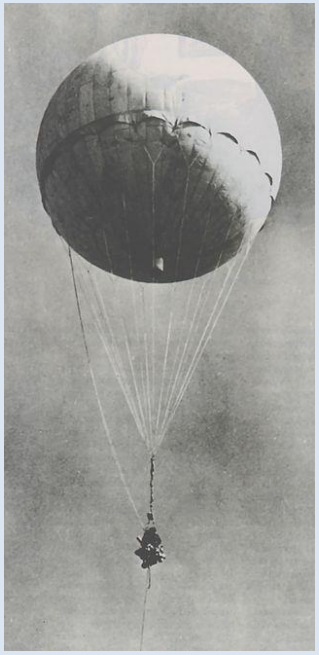
Tibetan high results in an upper-level anticyclone; located over n.India above the monsoon trough.

Moves in a south-southeast direction following the zone of maximum surface heating and low pressure

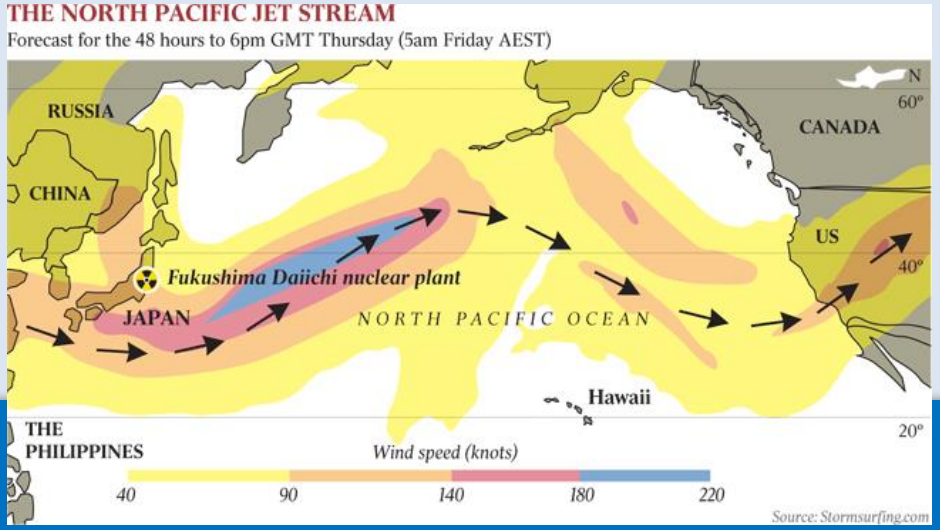


Tropical Jet streams …and World War II
Westerly in Winter

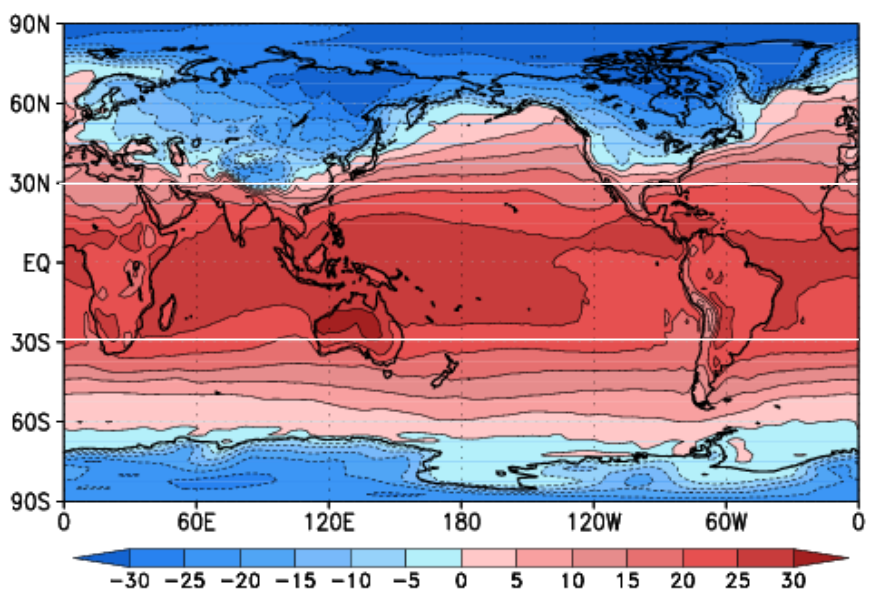




Japanese used the jet stream across Pacific to launch and drop balloon bombs in the US. About 9000 balloons were deployed, and 1000 reached destination after travelling 6000 miles, in 2–3 days!

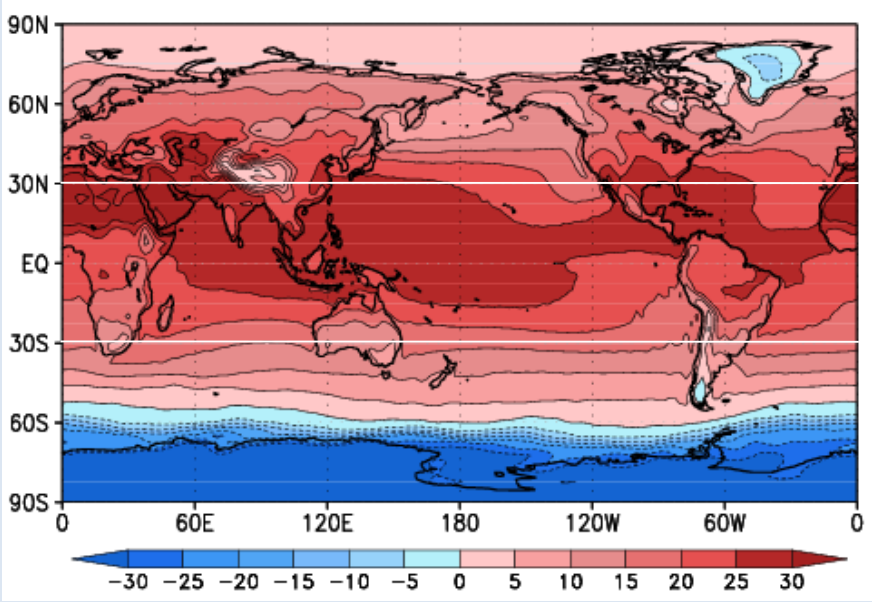


Monsoon, manifested by Surface Temperatures
Seasonal migration of solar insolation

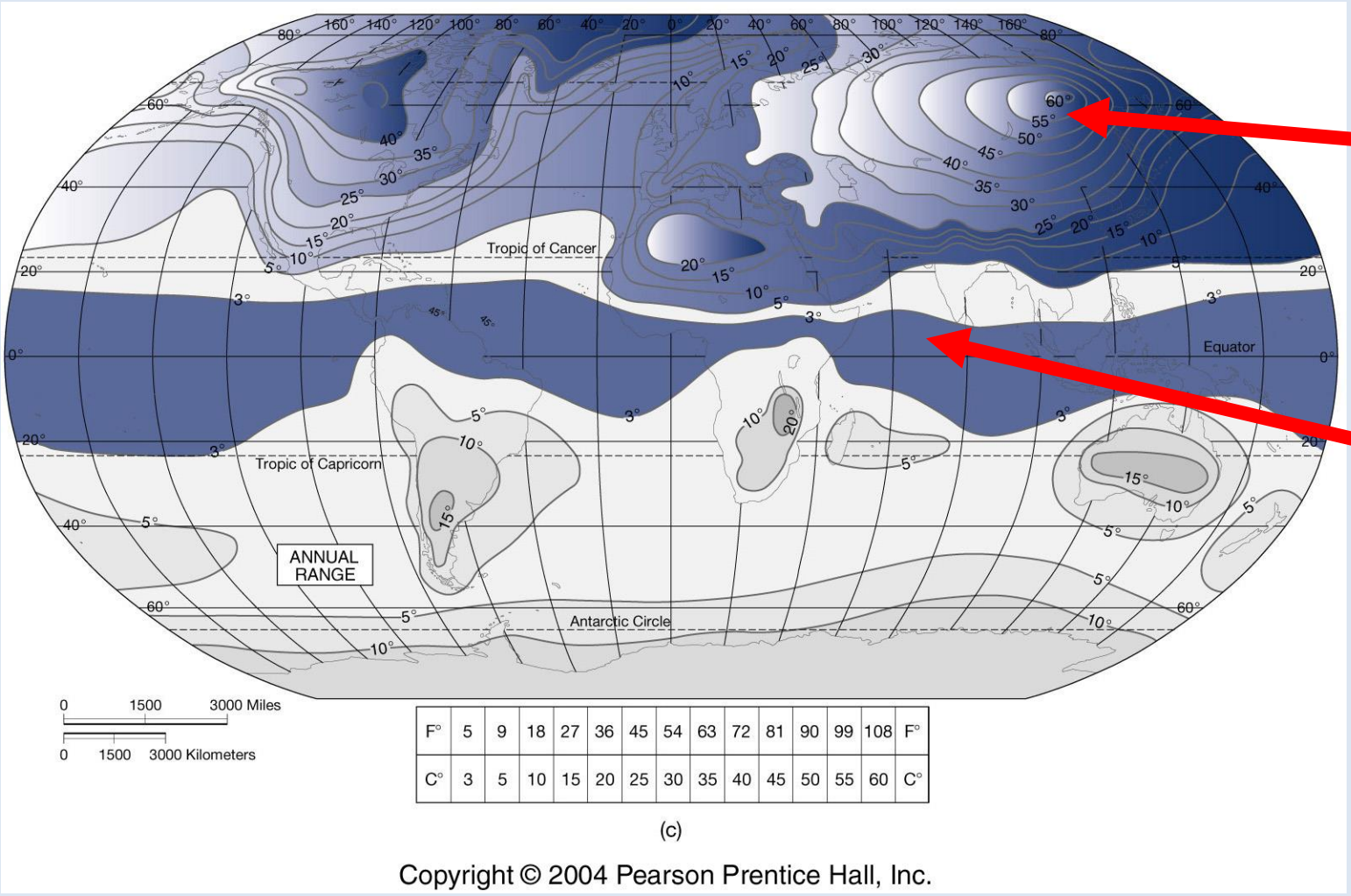


January

July



Monsoon, manifested by Thermal Contrast
Land and sea warms at different rates, sp.heat capacity



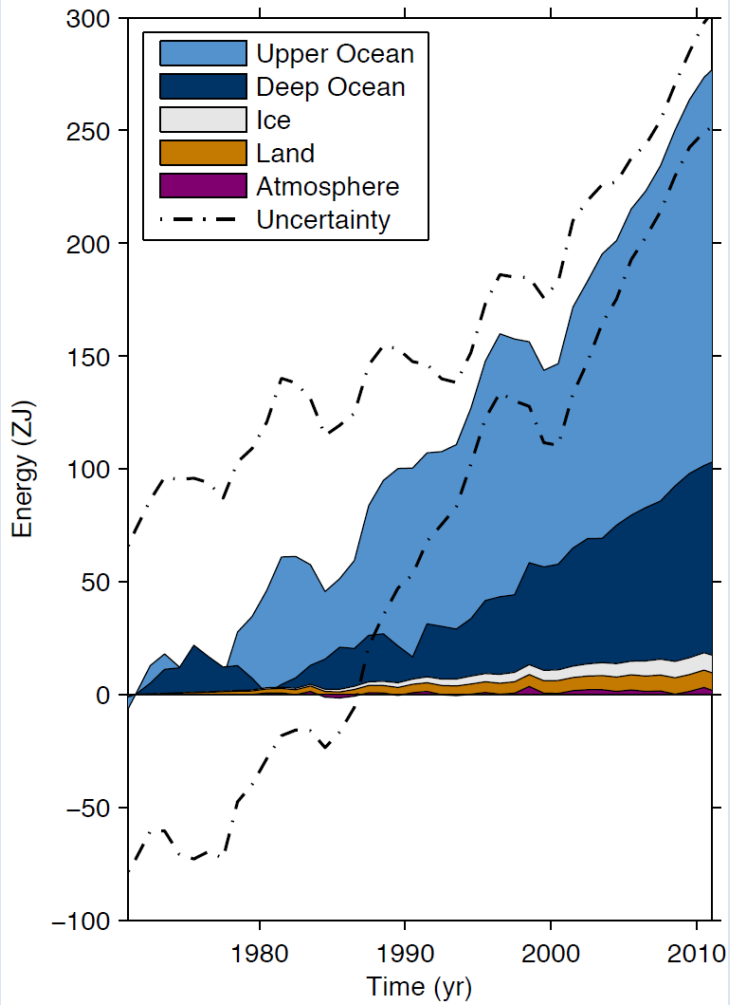
F°	5	9	18	27	36	45	54	63	72	81	90	99	108	F°
C°	3	5	10	15	20	25	30	35	40	45	50	55	60	C°

(c)

Tibetan plateau: range of 60° C

Ocean: range of 3 to 5° C

Ocean warming in a changing climate



During the past century…

1. Where has all the heat gone – Land/Atmos./Ocean?
2. Where in the Ocean?
3. Why is the Indian Ocean warming anomalously?

Monsoon:

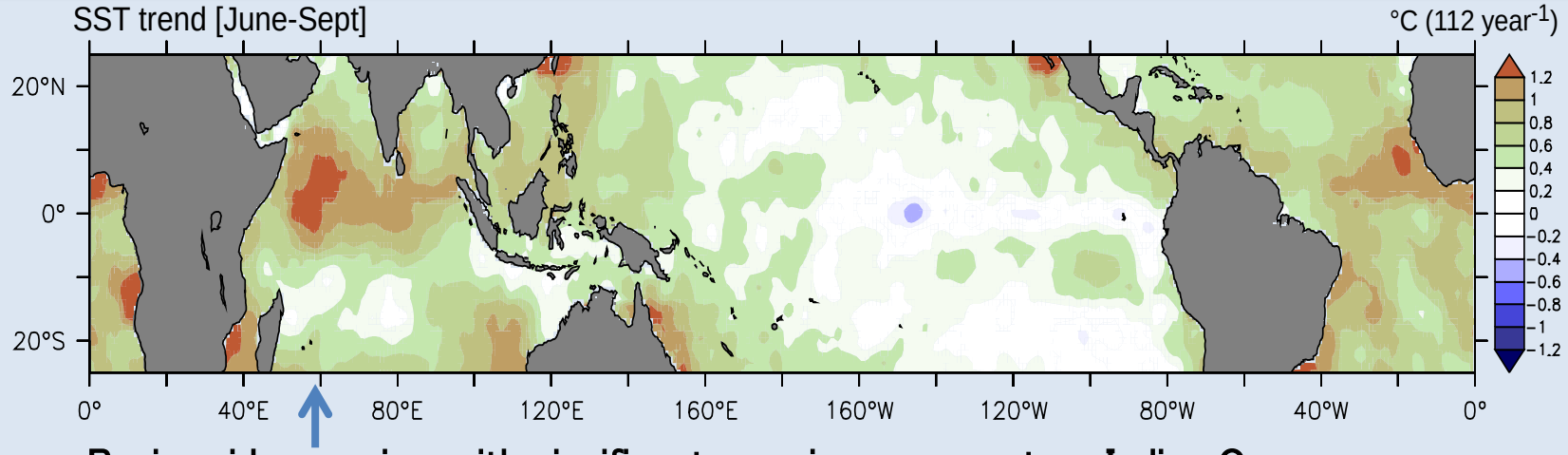
1. Have the monsoon drivers changed?
2. Is the South Asian Monsoon decreasing? Or increasing?
3. Role of Indian Ocean warming?
4. Interannual variability and Extreme events

Marine Productivity:

1. Is the marine phytoplankton decreasing?
2. Role of Indian Ocean warming?

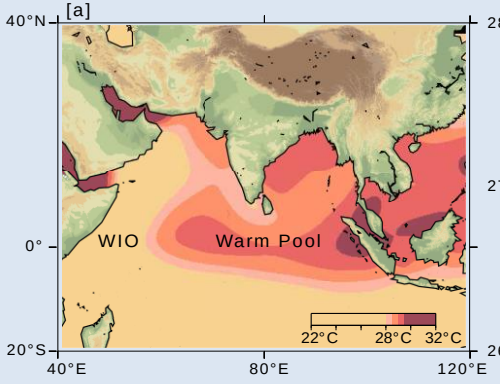
IPCC, *AR5,* 2013

Indian Ocean during the last century
western Indian Ocean warmed up to 1.2degC, in 100 yrs

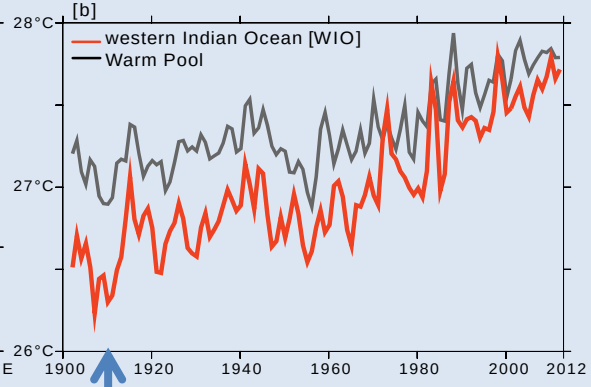


Basin-wide warming, with significant warming over western Indian Ocean.

SST Climatology



Time-series [1901-2012]



Monotonous **warming over west nullifies zonal SST gradient**

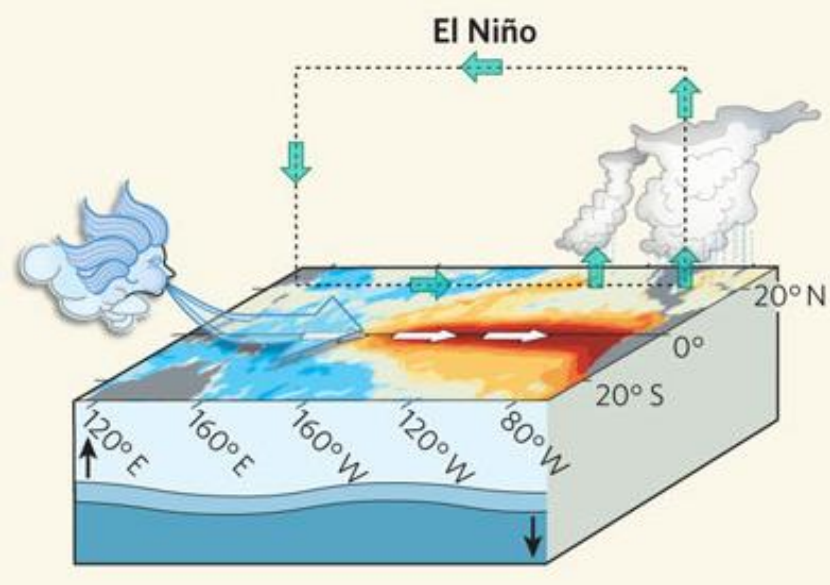
In early 1900s, the western Indian Ocean was much cooler than the warm-pool.

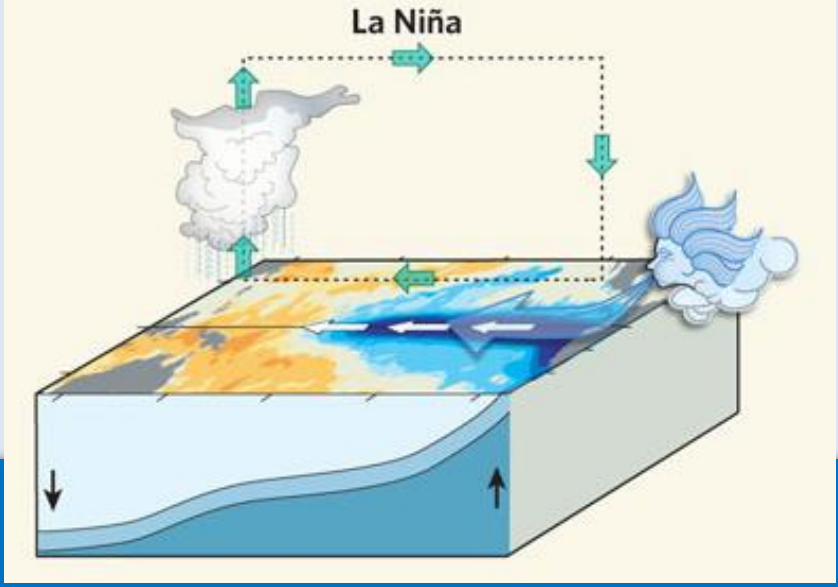
The monotonous **warming over west nullifies zonal SST gradient** – may influence monsoon dynamics.

Roxy et al. *J.Climate*, 2014

Asymmetry in ENSO forcing

Influence of El Niño > La Niña on Indian Ocean

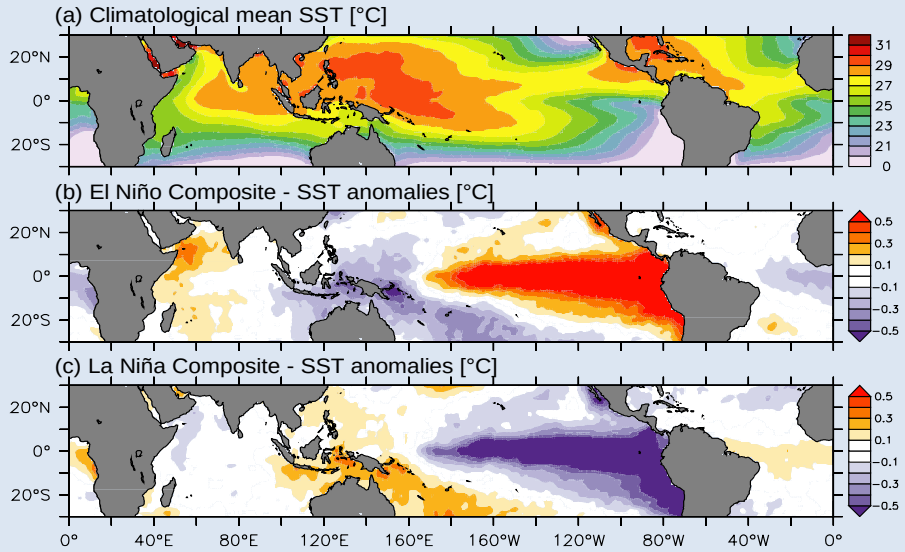




El Niño induce significant positive SST anomalies over Indian Ocean

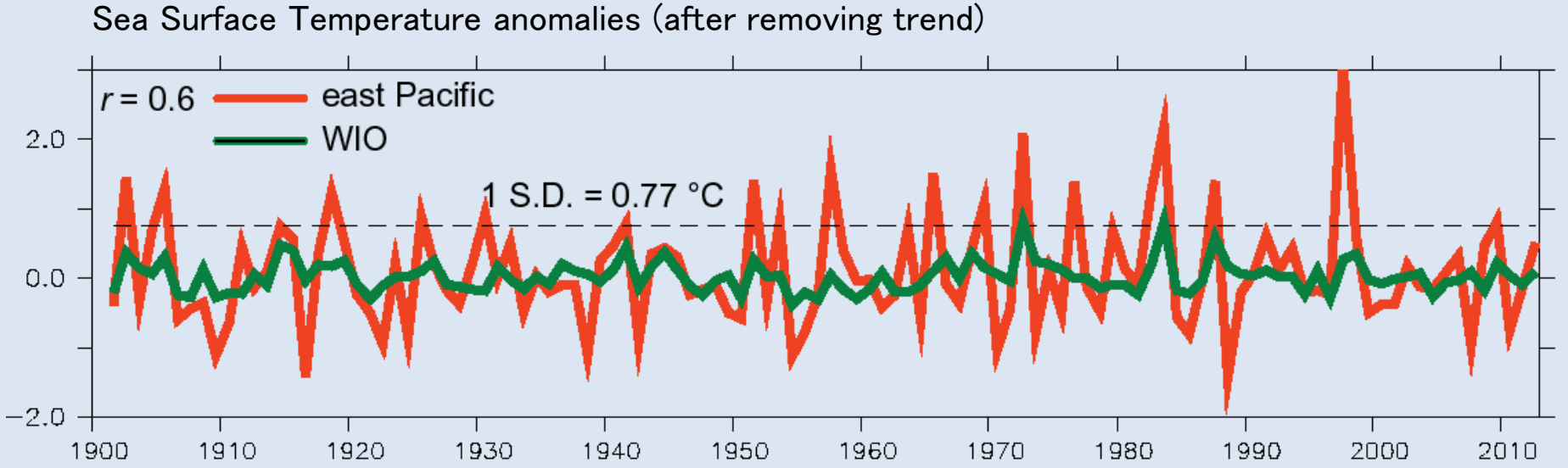
but...

La Niña events does not result in significant anomalies over the Indian Ocean



Skewness in El Niño forcing

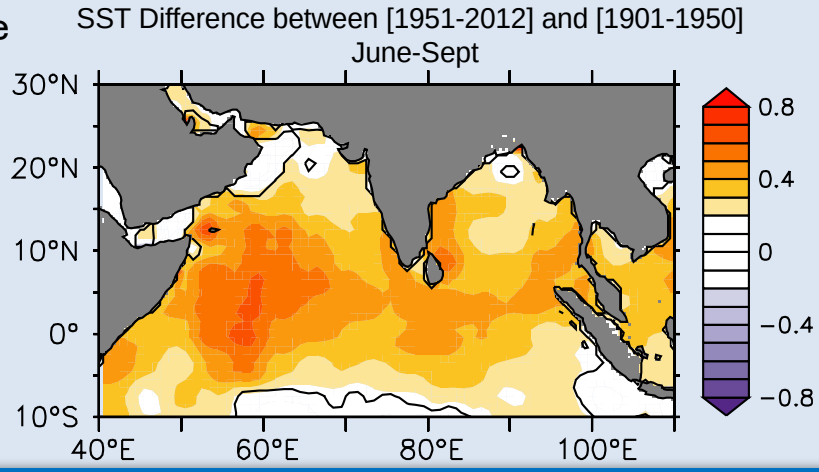
Increase in Frequency and Magnitude of El Niños



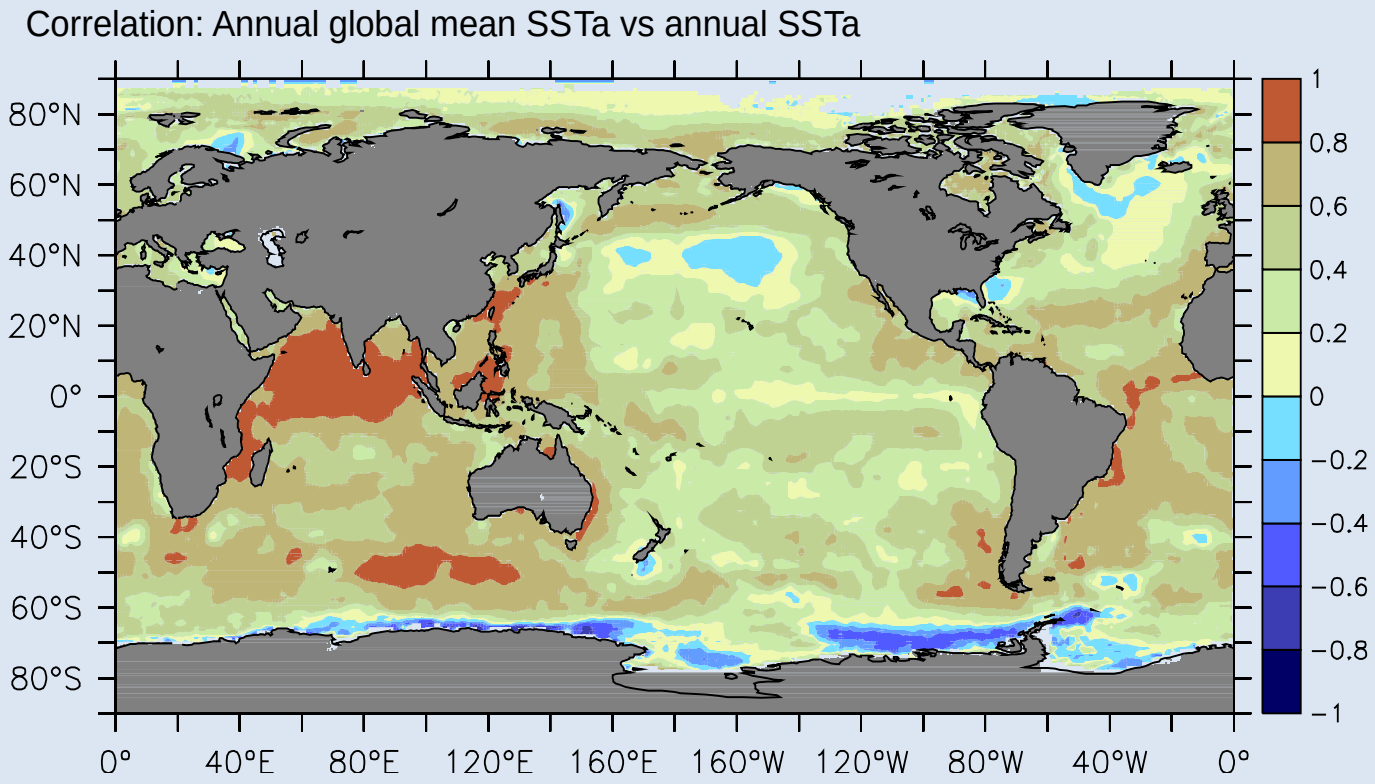
Increase in frequency and strength of El Niños, possibly due to increasing greenhouse gases.

Mini El Ninos in the Indian Ocean!

The warm events over Indian Ocean also has increased. Occasionally, they cross the El Niño criteria (0.77 degC).



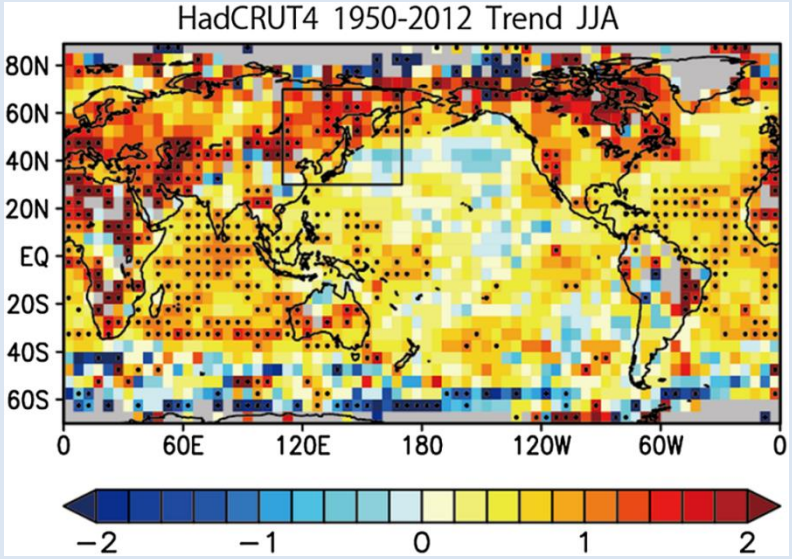
Largest contributor to global warming?
Indian Ocean warming "in phase" with global warming



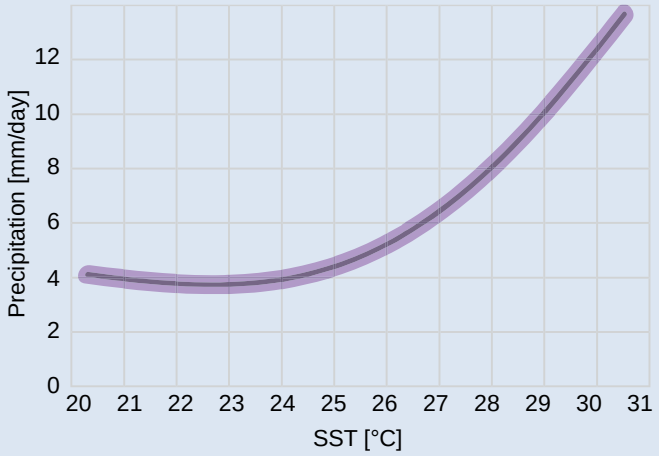
Roxy et al. *J.Climate*, 2014

Ideally, Increased land-sea contrast = more rainfall
Increased ocean warming = more rainfall

Increased land–sea thermal contrast

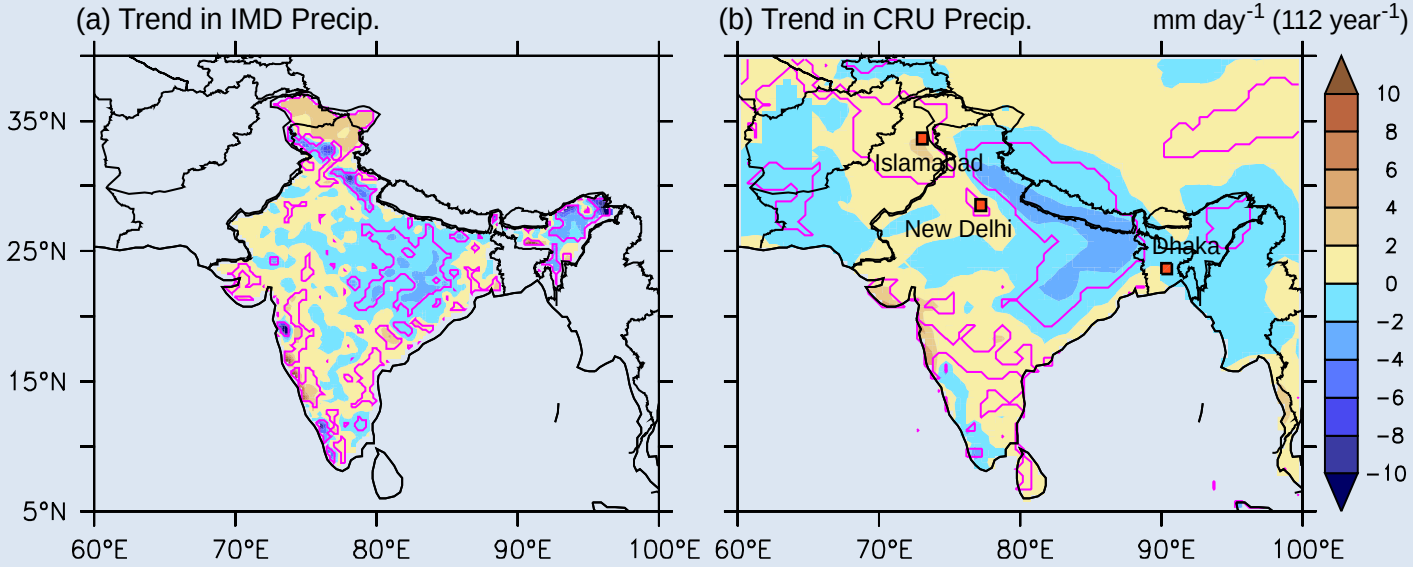


Increased ocean warming



Sutton et al. *GRL*, 2007; Hansen et al. *Rev.Geophys*, 2010
Gadgil et al.,*Nature*, 1984; Roxy,*Climate Dynamics*, 2013; Nair and Rajeev, *J.Climate*, 2013

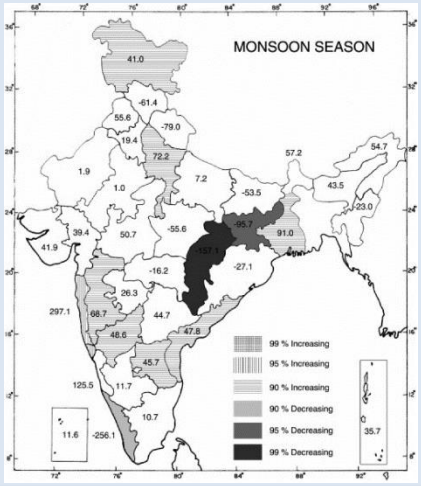
but it's a weak South Asian Monsoon
central India shows significant reduction in rainfall



Decreasing trend in precipitation from Pakistan through central India to Bangladesh. Significant over central Indian subcontinent (horse-shoe pattern)

Similar results from subdivisional station data: Guhathakurta and Rajeevan, 2008

Western Ghats show dipole like trends: Sandeep and Ajayamohan 2014

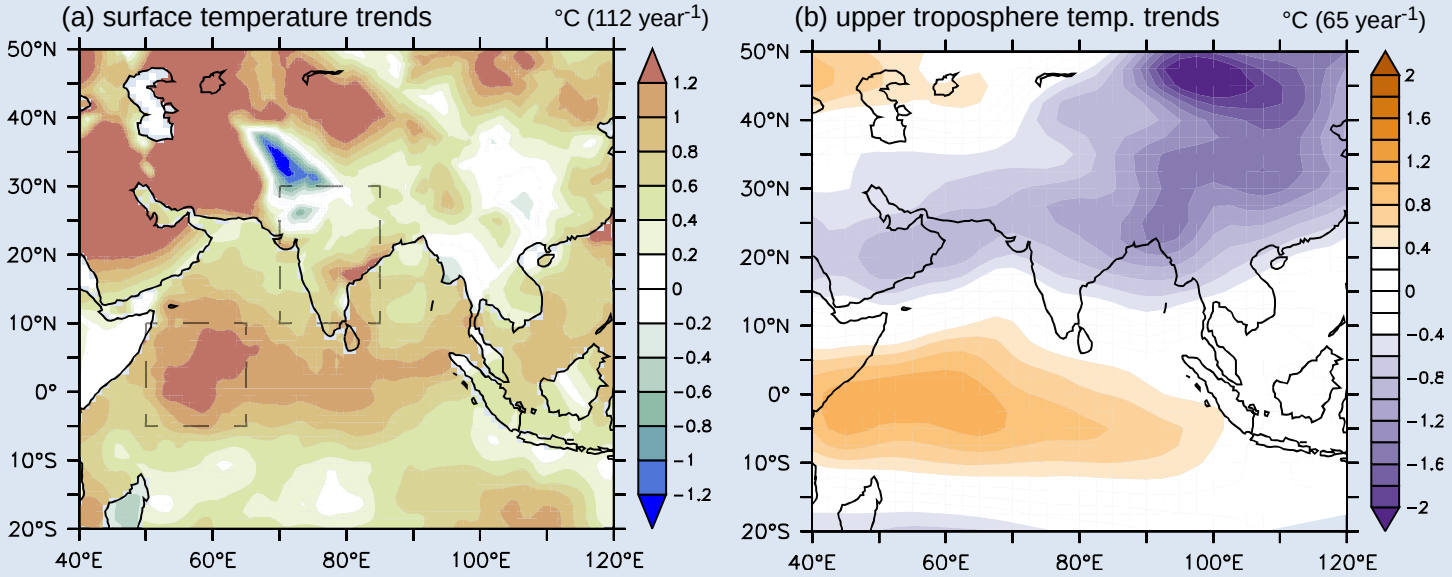


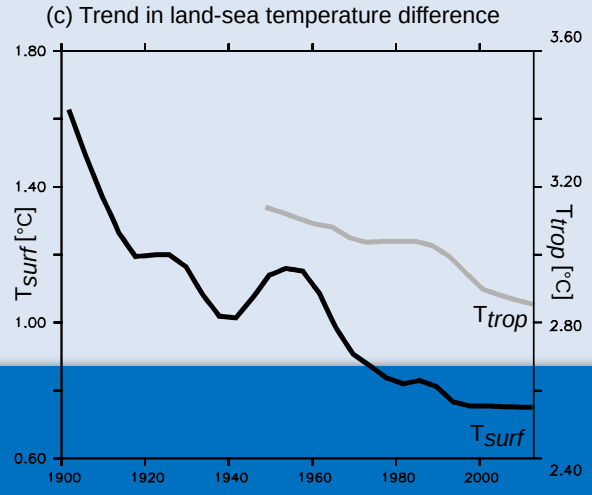
Guhathakurta and Rajeevan, *IJOC*, 2008; Sandeep and Ajayamohan, *Sci.Rep.*, 2014
Roxy et al. *Nature Communications*, 2015

Land-sea thermal contrast over South Asian domain

Indian Ocean–large warming, Subcontinent–suppressed warming

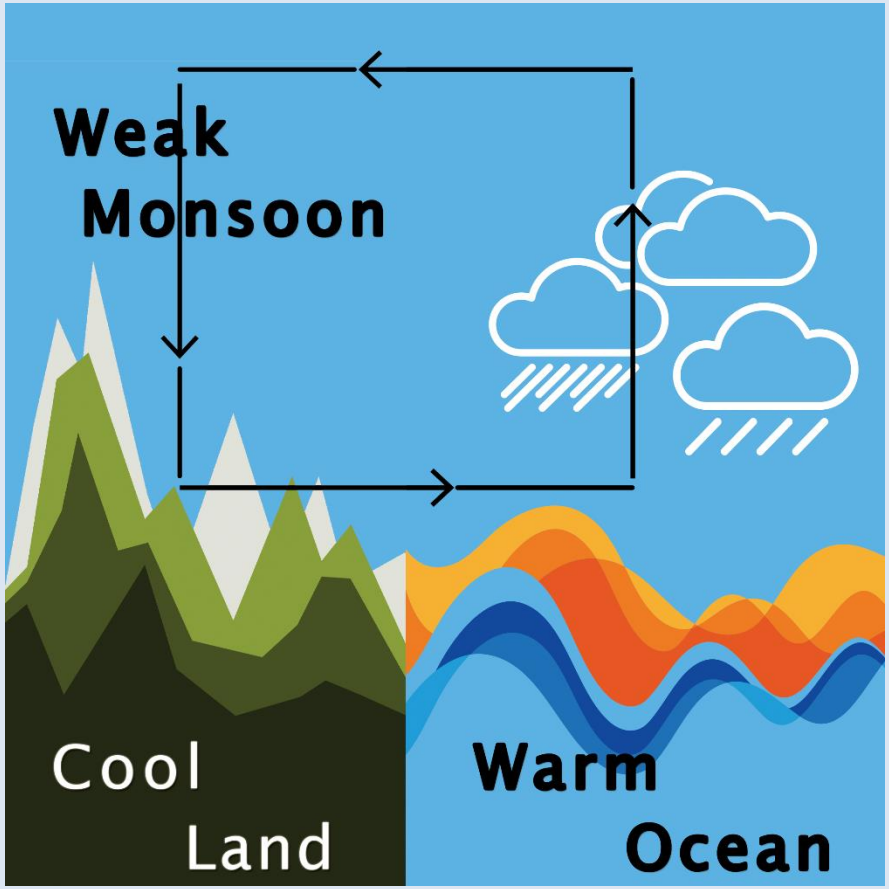
Though models and observations suggest increase in land–sea contrast over Northern Hemisphere due to global warming, it is different over South Asia/Indian Ocean.





Roxy et al. *Nature Communications*, 2015

Warm Ocean, Weak Monsoon



Future?

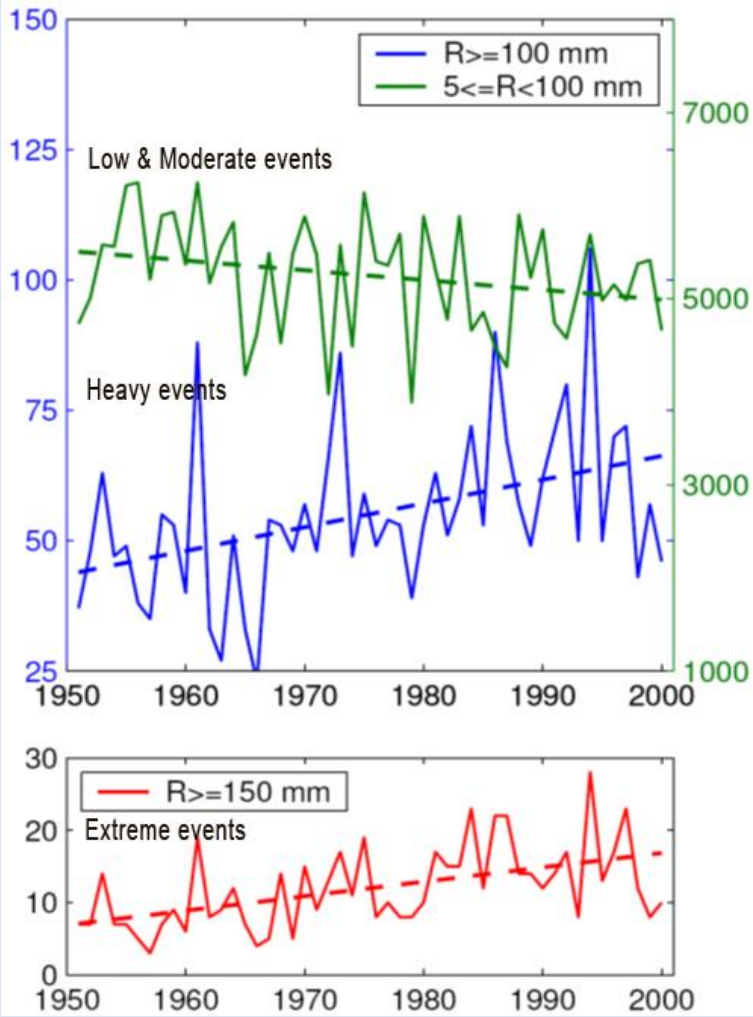
Future climate projections (CMIP5) suggest further warming of the Indian Ocean. Will the monsoon decrease further?

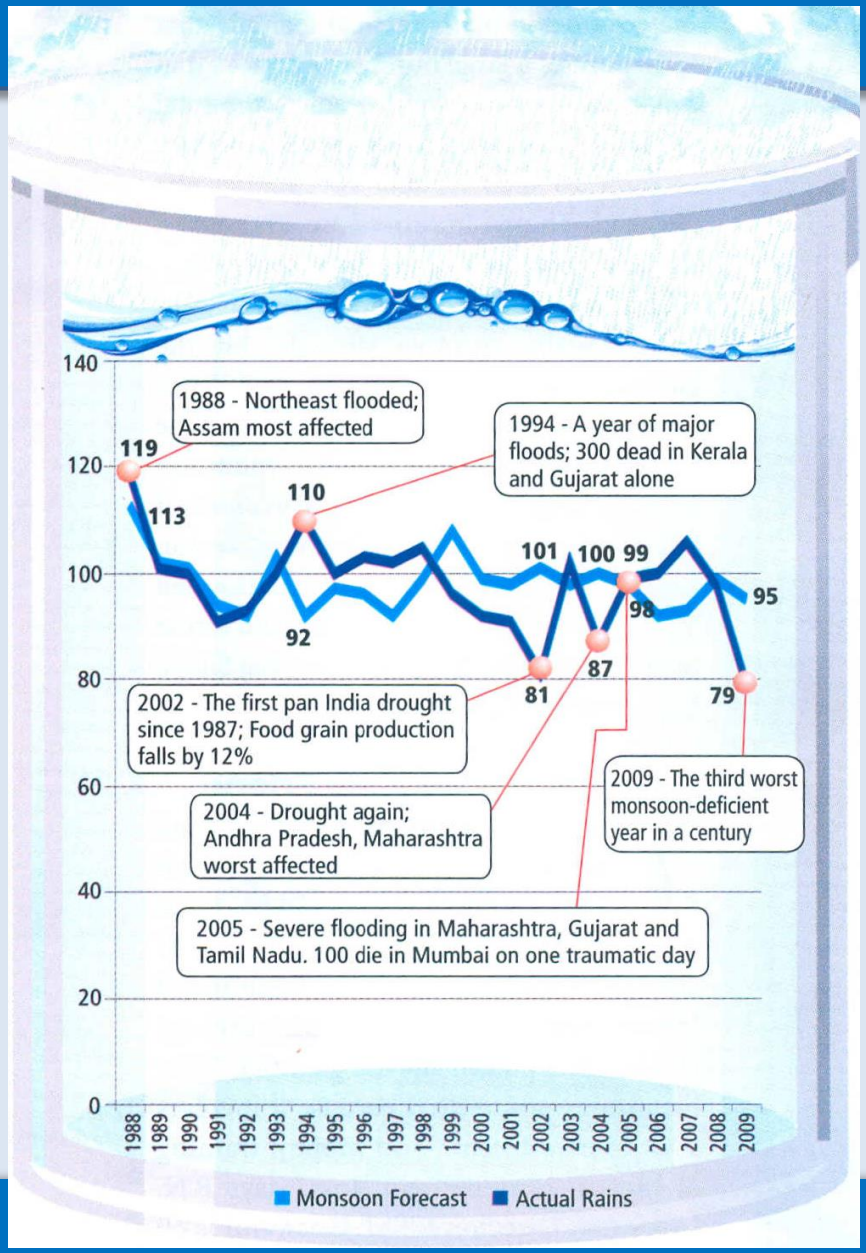
These future projections also suggest increasing monsoon rainfall (Sharmila et al 2015).

However it is to be noted that these models fail to reproduce the present day monsoon (Sabeerali et al 2014, Saha et al 2014)

Roxy et al. *Nature Communications*, 2015

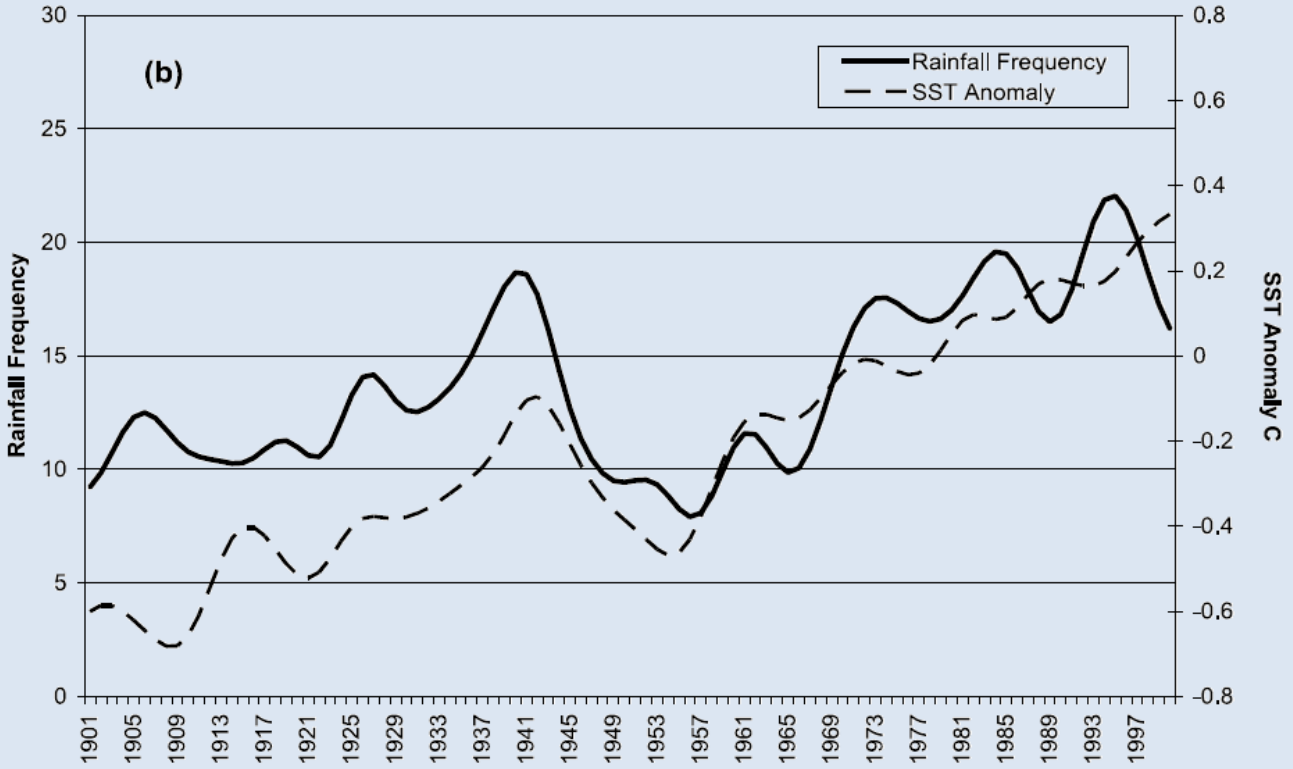
Extreme Rainfall Events





Goswami et al. *Science*, 2006

Indian Ocean warming and Extreme Rainfall Events

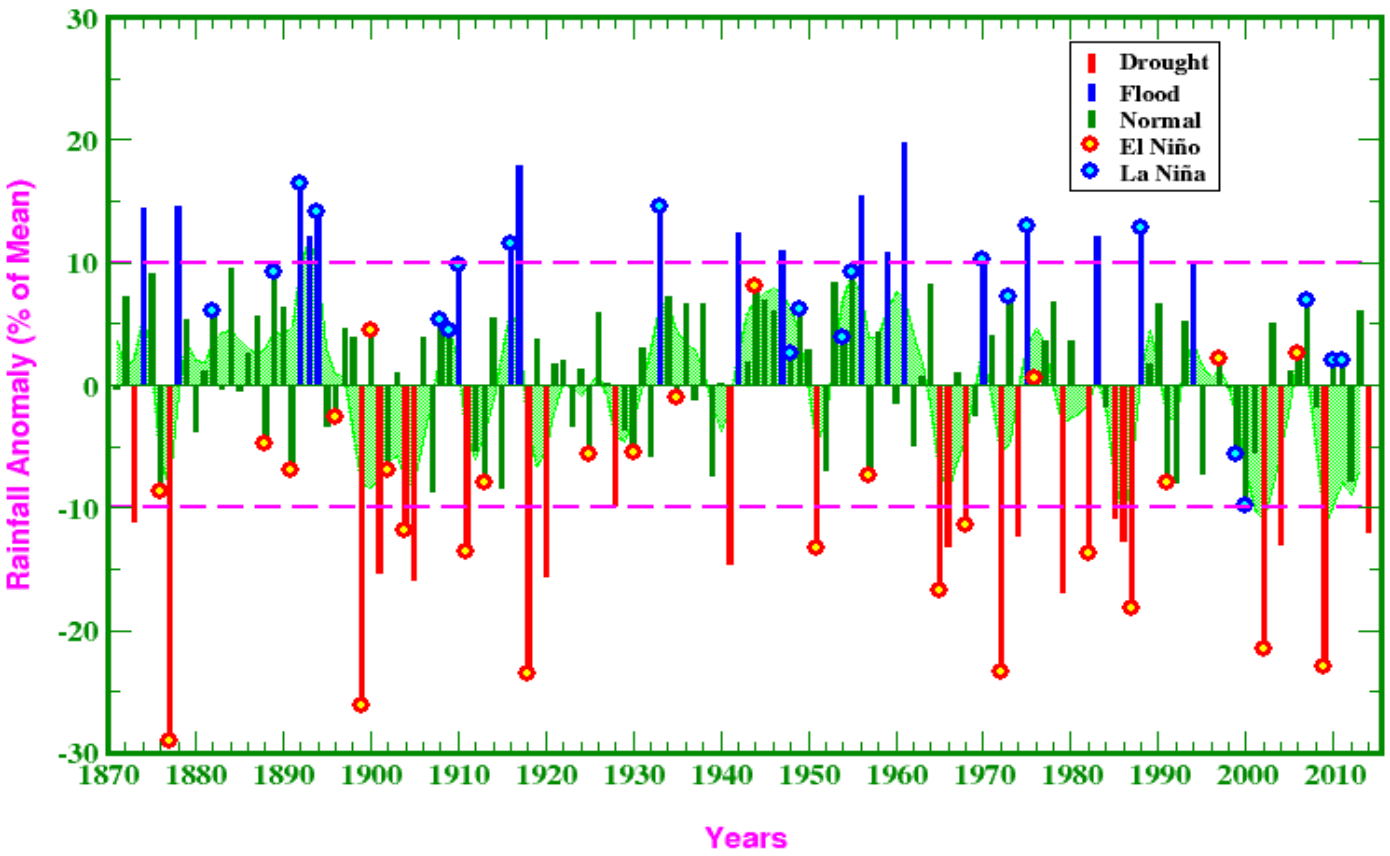


Extreme rainfall events over central India has increased. Shows association with increasing sea surface temperatures, which increases the available moisture.

It's difficult to say for certain that a particular extreme event for the monsoon is attributable to anthropogenic climate change – like the Pakistan floods of 2010 – but we do know that with a warming climate more moisture can be held in the atmosphere, leading to heavier rainfall when it does occur.

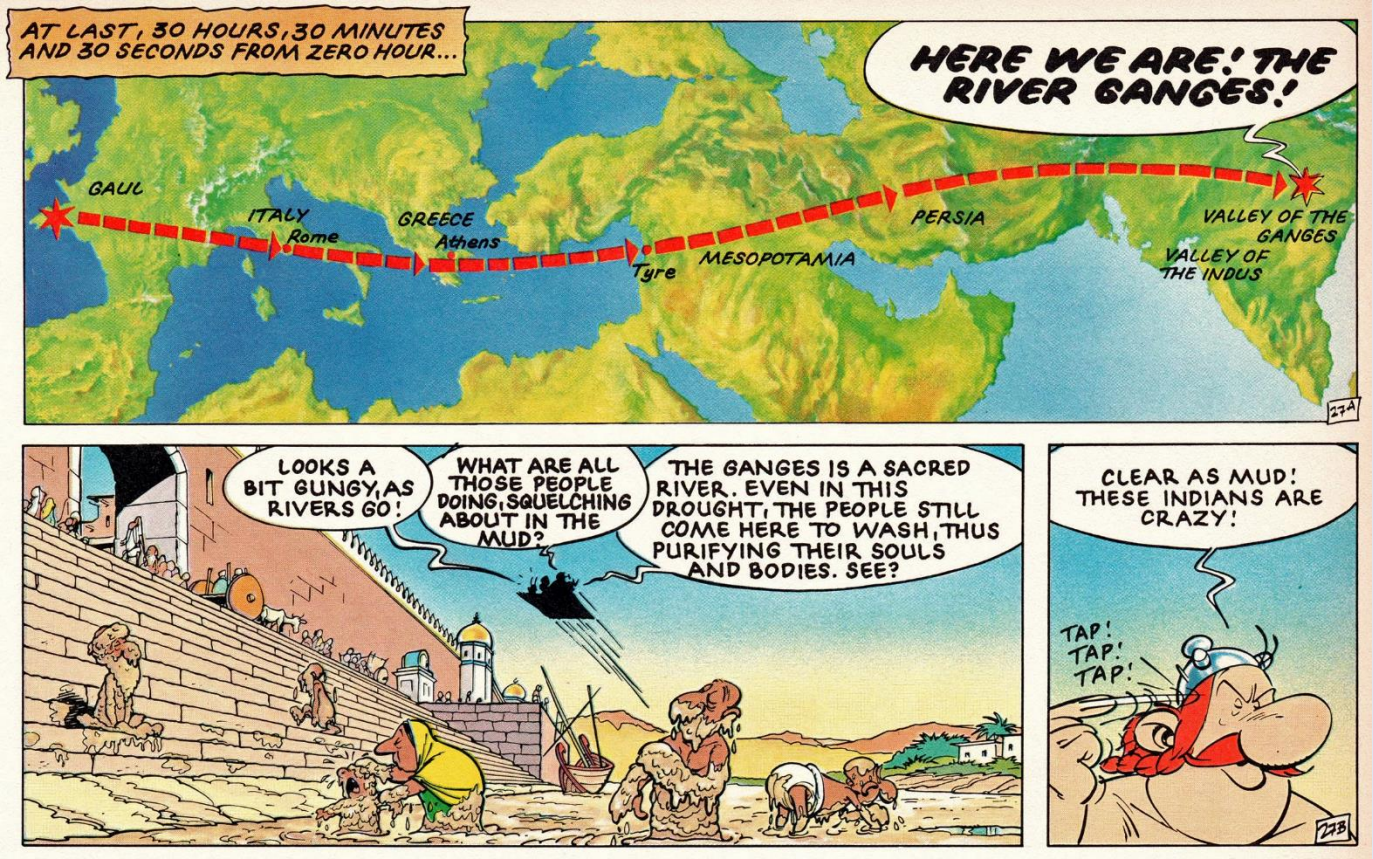
Rajeevan et al., *GRL*, 2008; Turner and Annamalai, *Nature Climate Change*, 2015

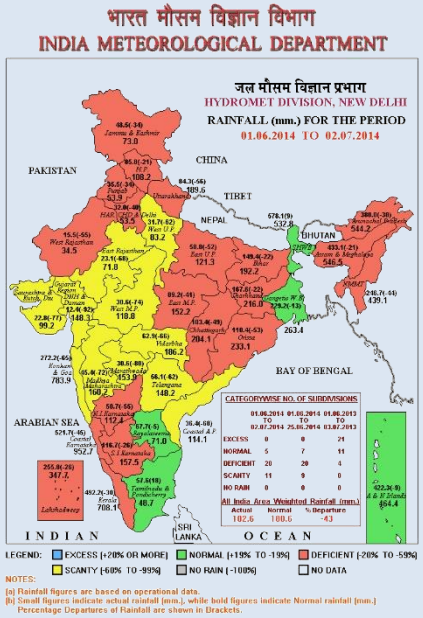
Interannual Variability of the Indian Monsoon
ENSO is a major driver

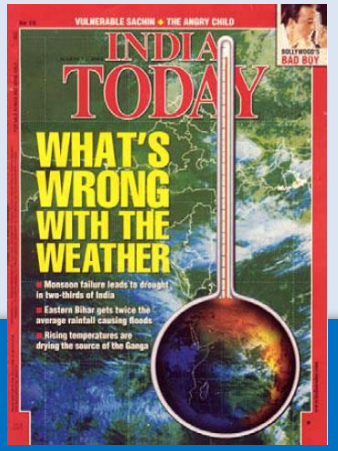


Generally, weak monsoon coincides with El Nino and strong monsoon with La Nina. Indian Ocean Dipole and El Nino flavors can change the scenario. Ashok et al. 2004, 2007

Monsoon 2014
- what went wrong?



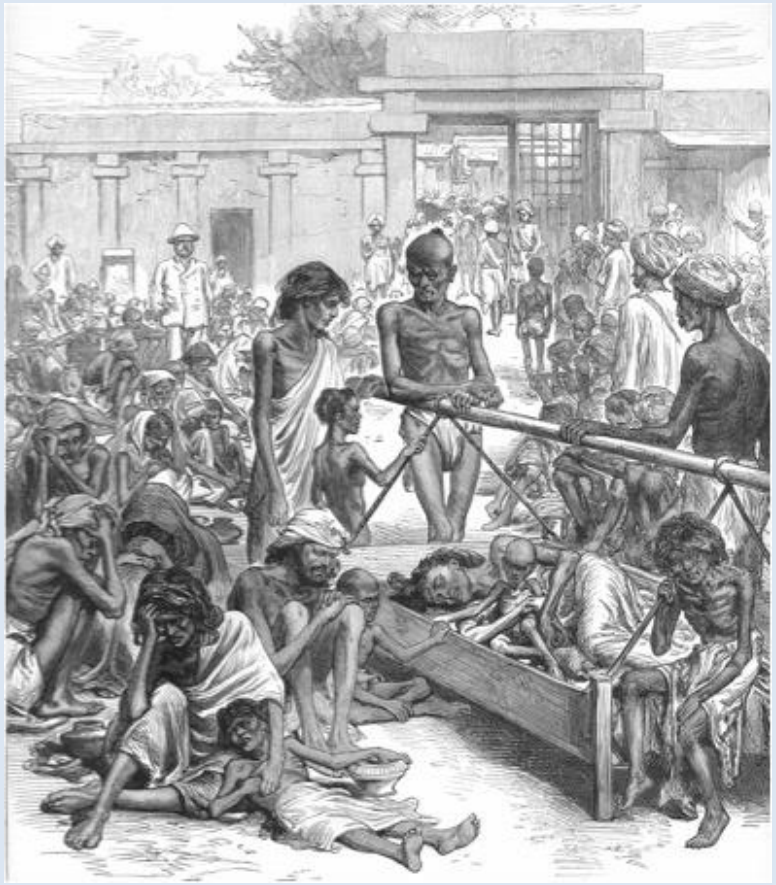




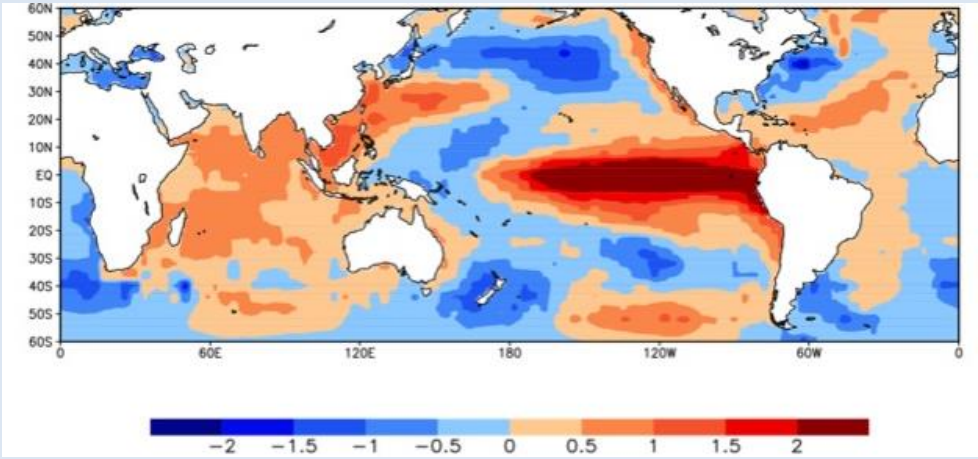
June–July 2015: deficient rains

Monsoon 2014
- El Niño conditions?

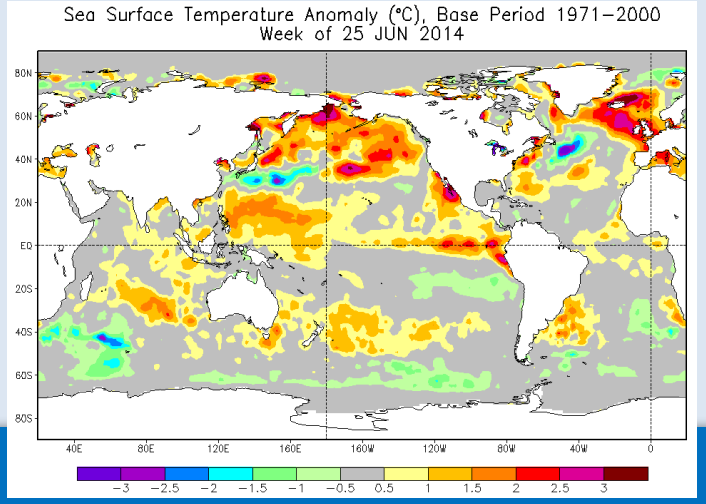
Great Famine of 1877–79



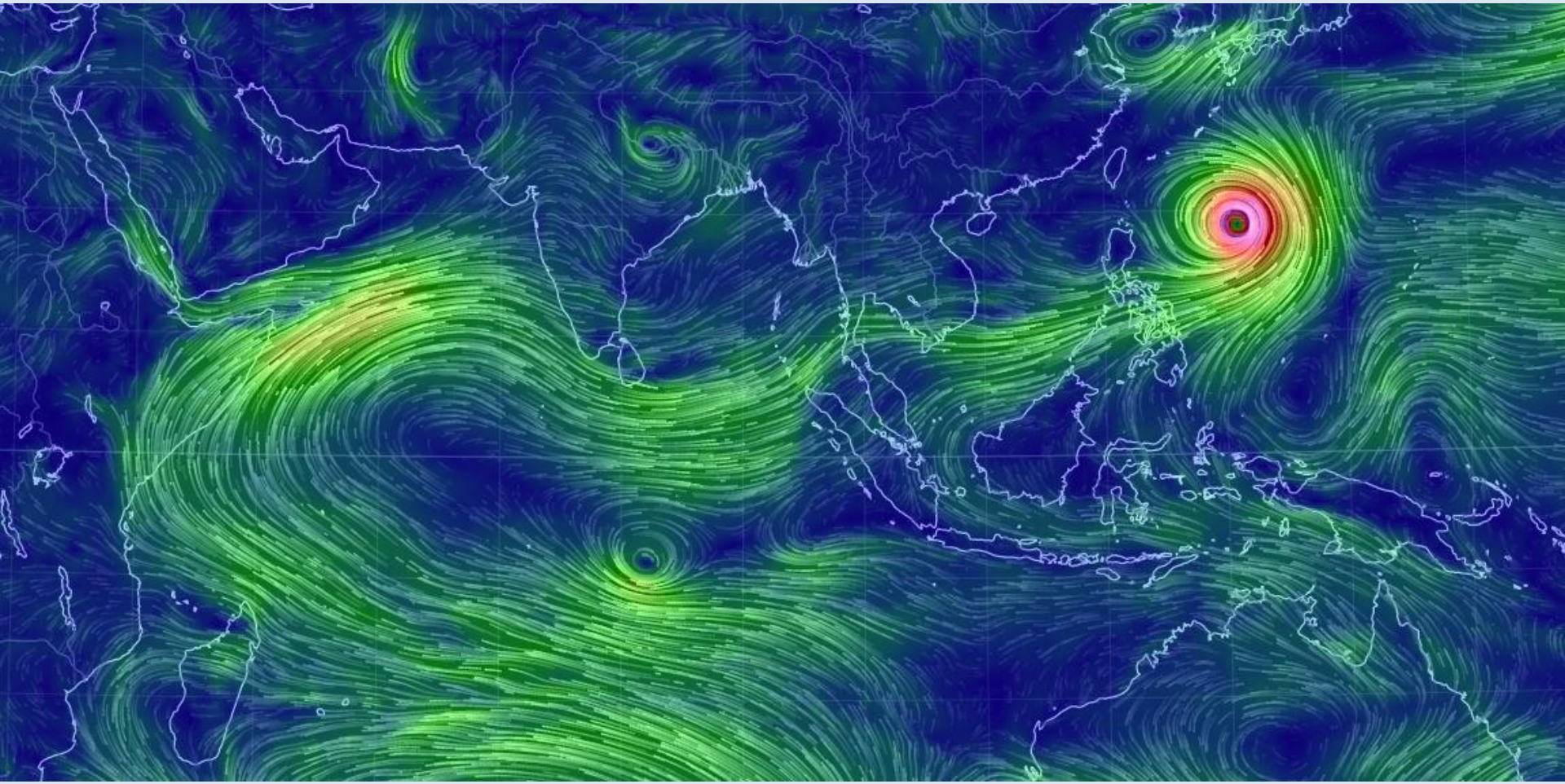
Sea surface Temp of 1877–79



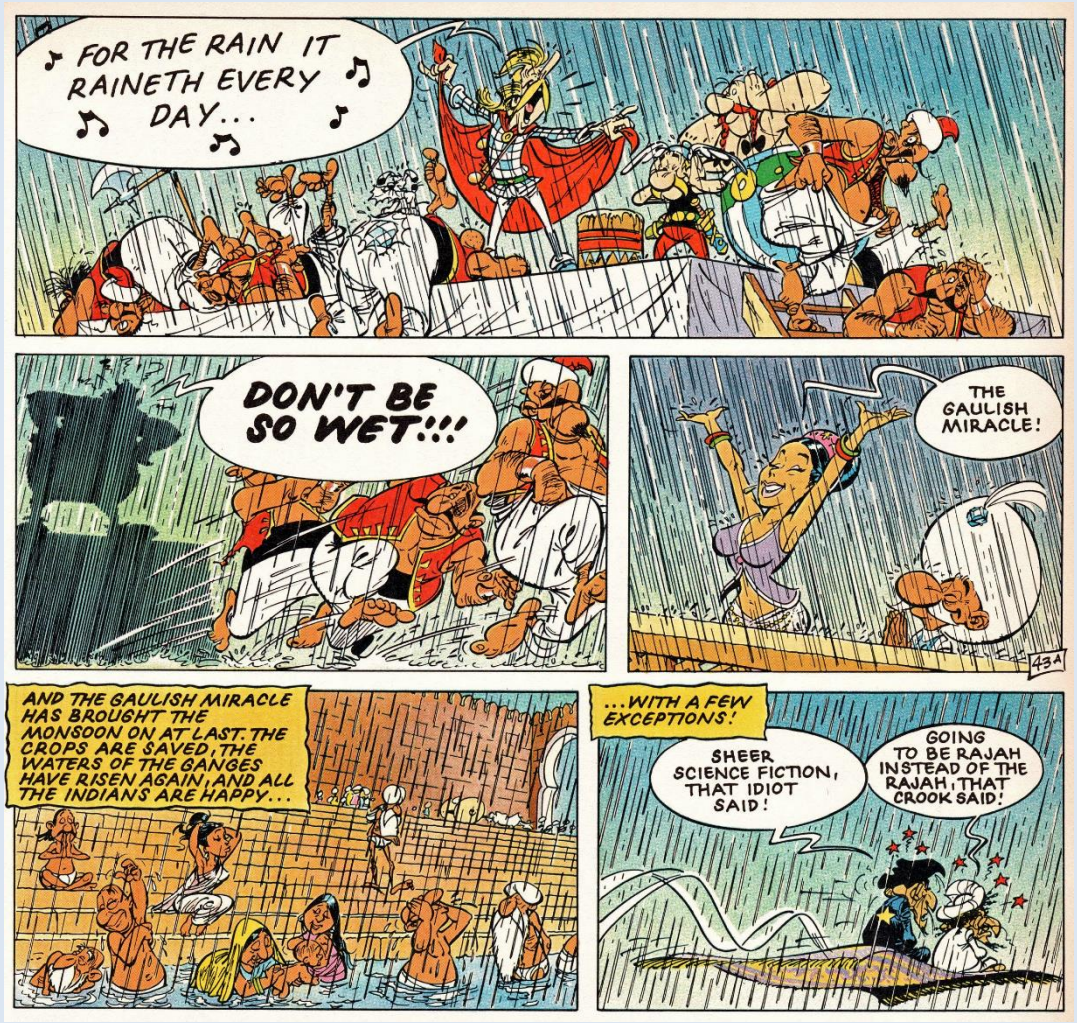
Sea surface Temp of summer 2014



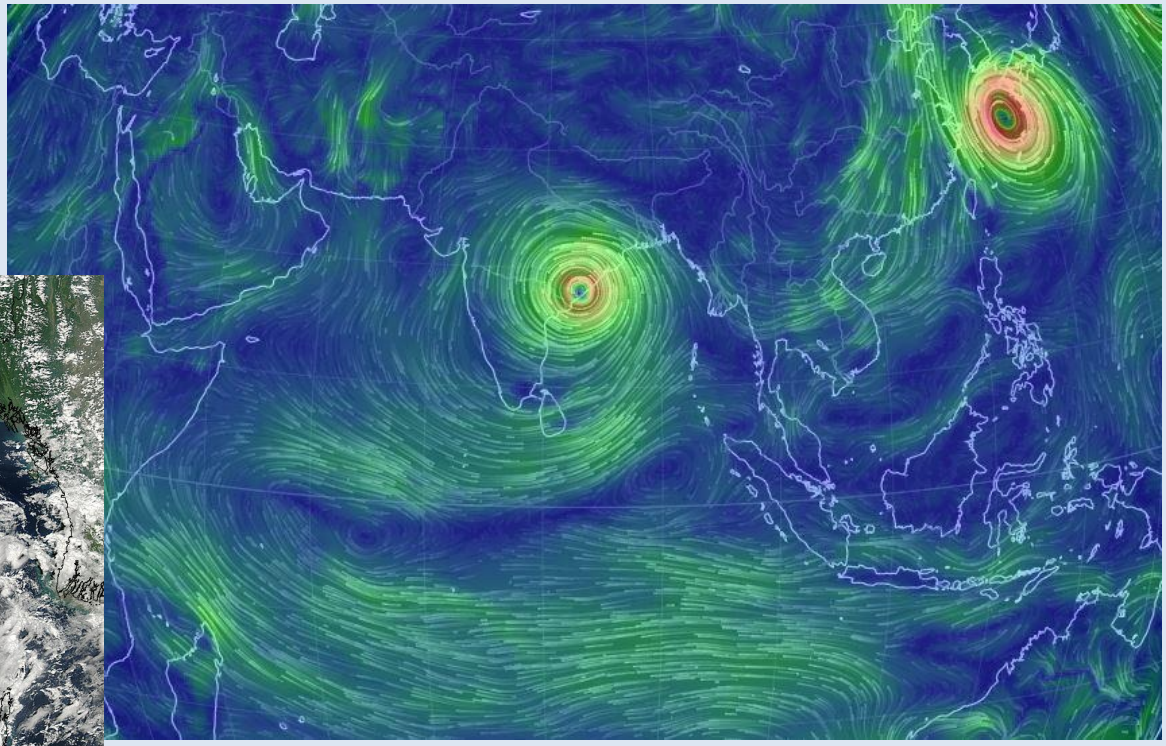
Monsoon 2014, early July
- super cyclone Neoguri pulling away the monsoon?

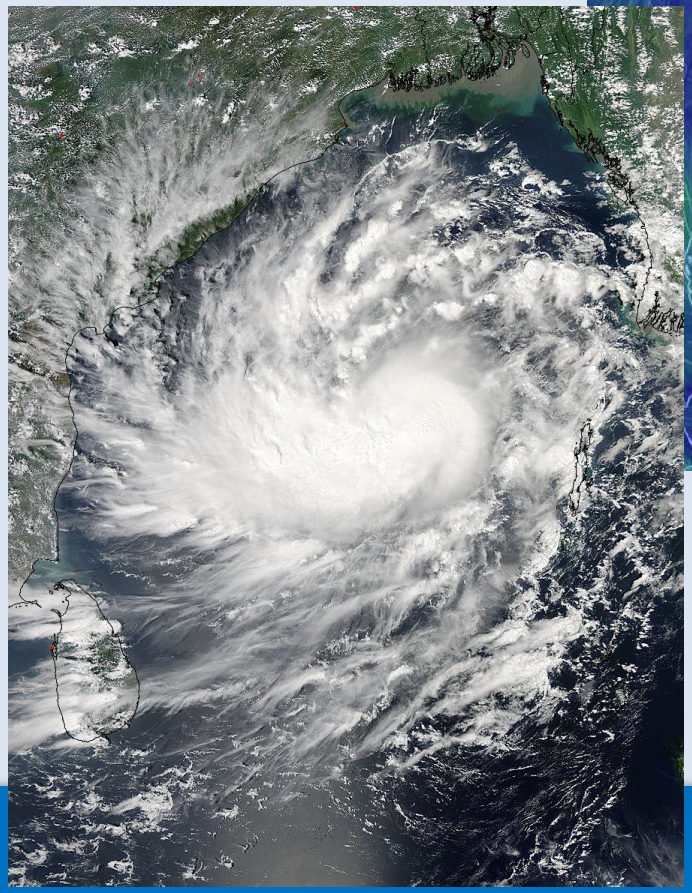


El Nino 2014 failed to develop
- Monsoon revived later into the summer season



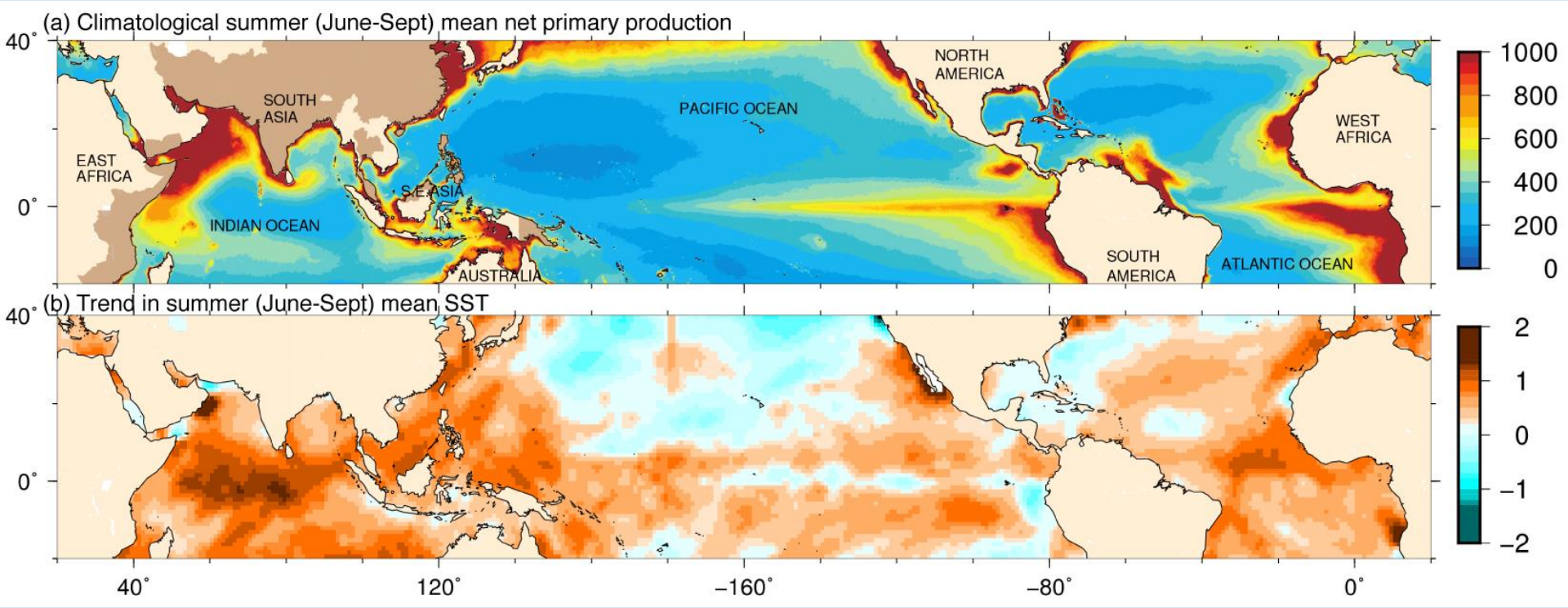
Monsoon 2014, early October
- super cyclone Hudhud bringing the rains in…





Warming – Marine Primary Production

western Indian Ocean is a highly productive region…

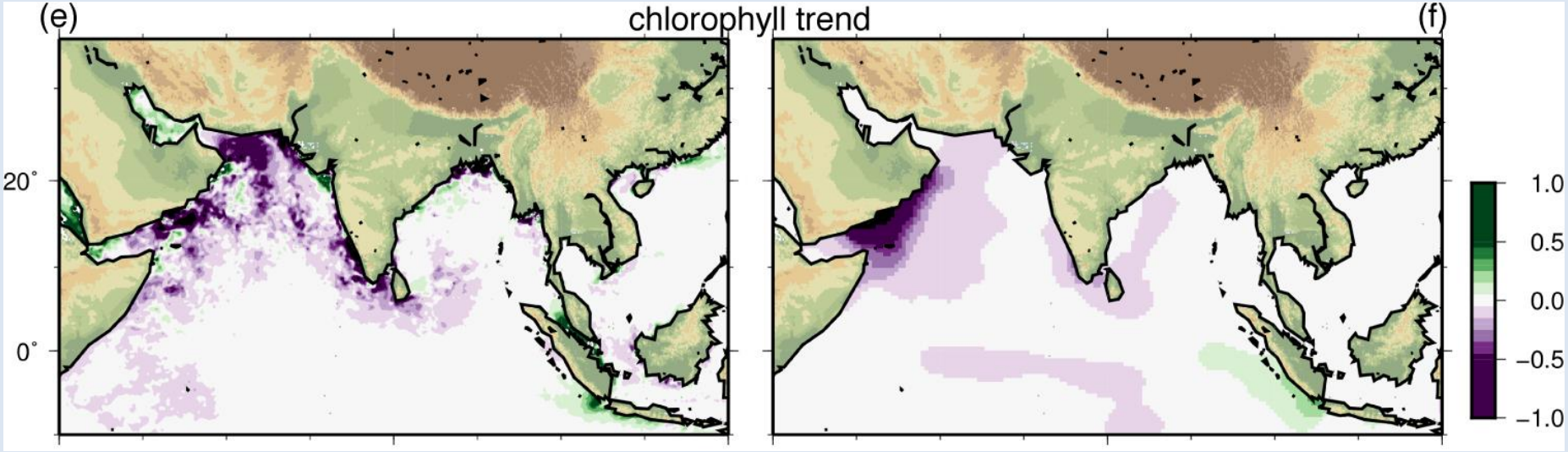


Roxy et al. *PNAS*, 2015, *Revised*

Reduction in Marine Primary Production
Chlorophyll trends in observations and simulations

Observations
1998 – present (~ 17 years)

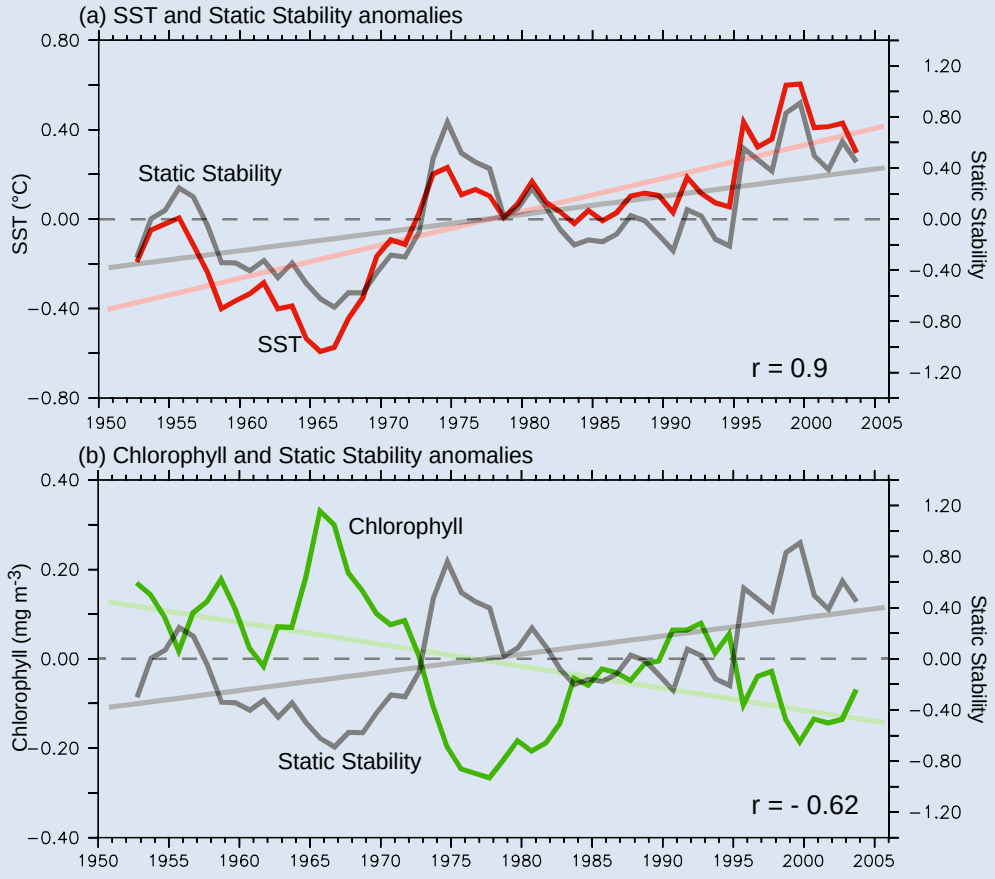
Historical Simulations:
1950–2005 (56 years)



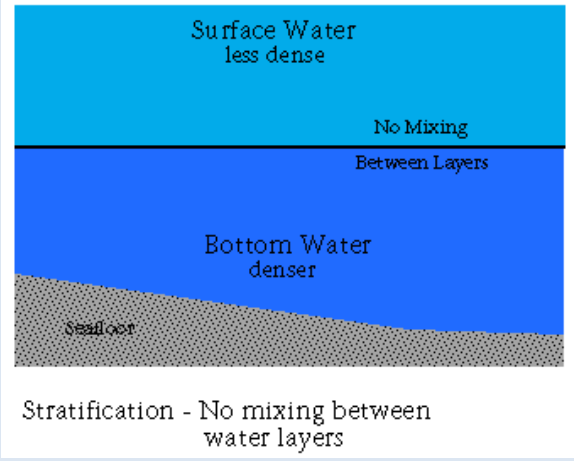
20–30% reduction in marine primary productivity over the western Indian Ocean

Warming stratifies the ocean - and suppresses the mixing of nutrients from the subsurface, reducing chlorophyll

Enhanced stratification due to increasing SST



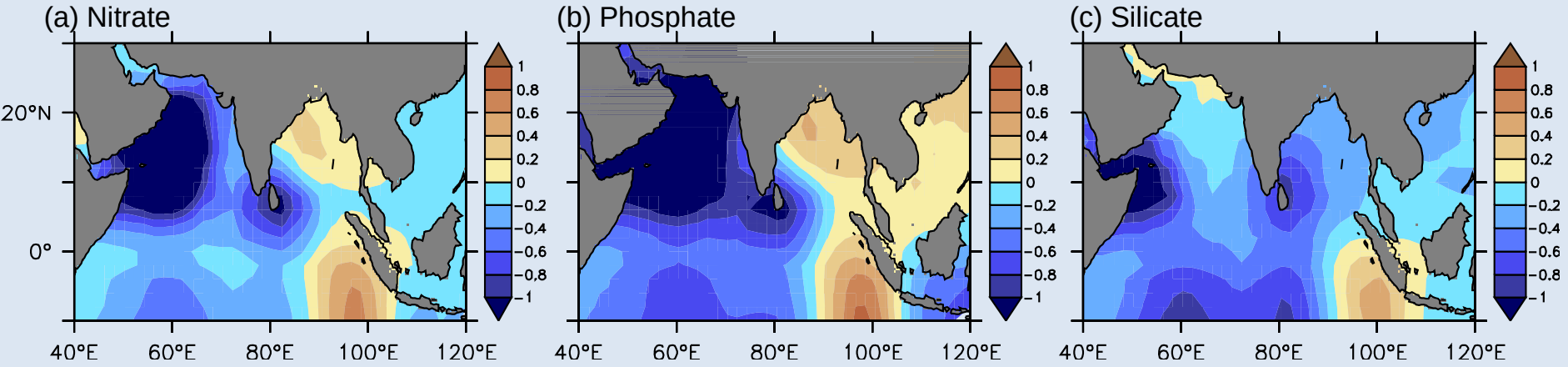
Stratification: surface warming results in "less dense" waters in the surface



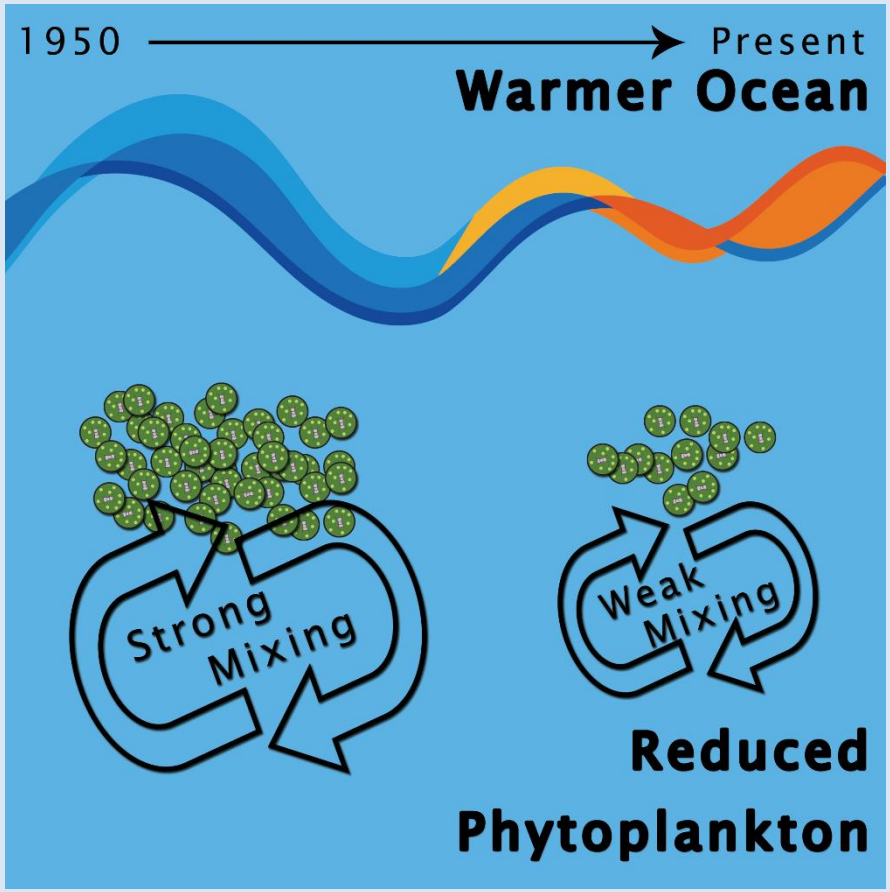
Stratification highly correlated to the reduction in Chlorophyll

Warming stratifies the ocean - and suppresses the mixing of nutrients from the subsurface, reducing chlorophyll

Nitrate, Silicate and Phosphate shows significant reduction over the same region where chlorophyll trend is negative



Warming Ocean, Reduced Marine Productivity

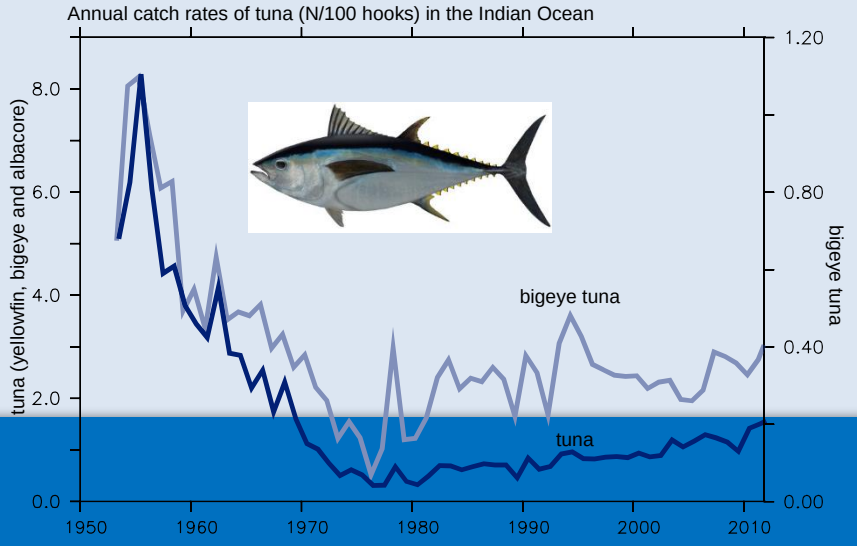


Future?

Future climate projections suggest further warming of the Indian Ocean.

Is Indian Ocean turning into an ecological desert?

Along with the stress from fisheries industries… reduced plankton might increase the fish stress



Roxy et al. *PNAS*, 2015, *Revised*

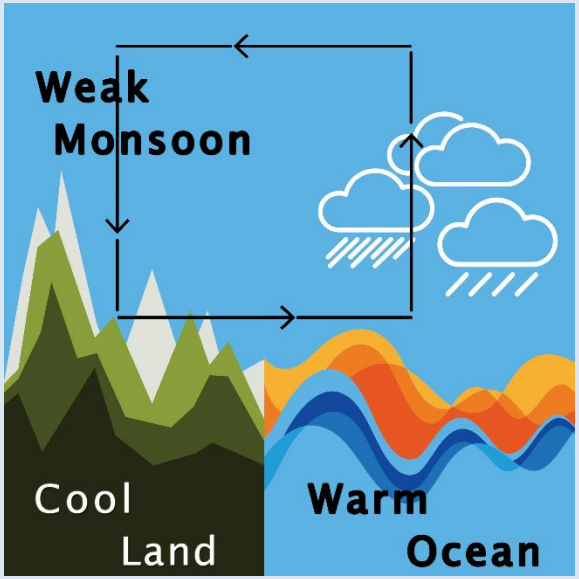
Indian Ocean warming – its extent, and impact on the Monsoon and Marine Productivity

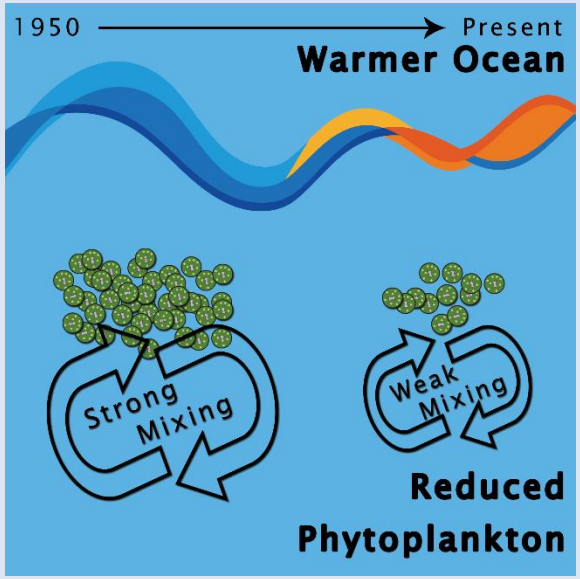
Indian Ocean warming:

- Strong, monotonous warming during the last century in the Indian Ocean

Potential Impacts:

- Weakening monsoon ~ desertification over the Indian subcontinent?
  - increasing extreme rainfall events and decreasing moderate rainfall events
- Reduced marine productivity ~ desertification in the Indian Ocean?





Thank You!